Refraction of Light

WARM UP

- **Light**: Light is a form of energy which produces the sensation of light.
- **Ray of light**: A line drawn in the direction of propagation of light is called ray of light.
- **Beam of light**: A group of parallel rays of light emitted by a source of light is called beam of light.
- **Laws of reflection**: 
  - The angle of incidence is equal to the angle of reflection
  - The incident ray, the normal to the mirror at the point of incidence and the reflection behind ray, all lie in the same plane
- **Plane mirror**: It always forms a virtual, erect, laterally inverted image formed behind the mirror and has the same size as the object.
- **Concave mirror**: Concave mirror is a part of a hollow sphere whose outer part is silvered and inner part is the reflecting surface.
- **Convex mirror**: Convex mirror is a part of a hollow sphere of which the spherical mirror forms a surface and inner part is silvered.
- **Spherical mirror**: A reflecting surface which is a part of a sphere in which inner or outer surface is reflecting.
- **Centre of curvature**: The centre of a hollow sphere of which the spherical mirror form a part is called centre of curvature. It is denoted by C.
- **Radius of curvature**: The radius of a hollow sphere of which the spherical mirror forms a part is called radius of curvature. It is denoted by R.

TRUE (or) FALSE

1. Light is an electromagnetic radiation.
2. Light always behaves like a wave.
3. The effective width of a spherical mirror from which reflection can take place is called its aperture.
4. A convex mirror produces a virtual, erect and magnified image.
5. Laws of reflection are applicable to all types of reflecting surfaces.
6. According to sign conventions, the distance measured in the direction of incident light is taken as negative.
7. The pole of a spherical mirror is the centre of the mirror.
8. When an object is at the centre of curvature of concave mirror, the image formed will be virtual and erect.
9. If an object of height 1 cm is placed near a concave mirror of magnification 10, then the height of the image will be 10 cm.
10. A convex mirror is used in the ophthalmoscope.

FILL IN THE BLANKS

11. A concave mirror gives real, inverted and same size image if the object is placed at ______
12. A concave mirror gives virtual, erect and enlarged image if the object is placed ______
13. Focal length of combination of two thin lenses of power+6D and -2D is ______
14. The radius of curvature of a mirror is 20 cm, its focal length is ______
15. An incident ray makes $60^\circ$ angle with the surface of the plane mirror the angle of reflection is __________

16. If the linear magnification in case of spherical mirror is greater than one, then the image formed is __________

**MULTIPLE CHOICE QUESTIONS**

17. The number of images observable between two parallel mirrors is
   1) 6          2) infinite          3) 2          4) 4

18. The number of images formed by two plane mirrors inclined at an angle $60^\circ$ of an object placed symmetrically between mirrors is
   1) 5          2) infinite          3) 6          4) 7

19. How many images of himself does an observer see if two adjacent walls and the ceiling of a rectangular room are mirror surfaced?
   1) 6          2) 7          3) 3          4) 5

20. A thick plane mirror shows a number of images of the filament of an electric bulb. Of these, the brightest image is the
   1) last          2) fourth          3) first          4) second

21. A light bulb is placed midway between two plane mirrors inclined at an angle of $40^\circ$. The numbers of images formed are
   1) 5          2) 4          3) 6          4) 8

22. Choose the wrong statement.
   1) A concave mirror can form a magnified real image.
   2) A concave mirror can form a magnified virtual image
   3) A convex mirror can form a diminished virtual image
   4) A convex mirror can form a diminished real image

23. A man 180 cm high stands in front of a plane mirror. His eyes are at a height of 172 cm from the floor. Then to see his full image for minimum length of mirror, the lower end of the mirror should be placed at a height of
   1) 86 cm from the floor          2) 94 cm from the floor
   3) 4 cm from the floor          4) 8 cm from the floor

24. A man standing on the road in front of a large window glass pane sees his image bigger than himself. The glass pane is
   1) Convex outside          2) cylindrical outside          3) plane          4) concave outside

25. It is desired to photograph the image of an object placed at a distance of 3 m from a plane mirror. The camera, which is at a distance of 4.5 m from the mirror, should be focused for a distance of
   1) 6 m          2) 7.5 m          3) 3 m          4) 4.5

26. An object 5 cm long and a pencil 10 cm long are placed in front of a pin hole camera such that their images have the same length. The ratio of the distance of the object from the pin hole to that of the pencil is
   1) 5:2          2) 1:4          3) 3:2          4) 1:2

**SYNOPSIS**
Refraction of Light

The bending of light rays when they pass obliquely from one medium to another medium is called Refraction of light.

This phenomenon of light can be easily demonstrated by the following activity.

ILLUSTRATION – 1

A pencil appears bent and short, when immersed obliquely (at an angle) in water. Take a pencil and dip it obliquely in a Beaker, half filled with water. The pencil appears to be bent or displaced at the surface of separation between the two media (water - air interface). This apparent bending or displacement of pencil is due to the refraction of light. The ray coming from the portion of the pencil is due to the refraction of light. The ray coming from the portion of the pencil above and below the water reaches our eyes from different directions and the pencil appears to be bent or broken.

Explanations: Consider a ray of light starting from the end point B of the pencil passing from water to air at point D and reaching the eye. It appears to be coming from a different point C. The point C is therefore the virtual image of the end point B of the pencil and lies exactly above point B. In the same way each point on the portion AB (dipped in water) of the pencil has a corresponding virtual image above the point. Thus the virtual image of the portion AB of the pencil appears at AC due to refraction of light.

Refraction of light from a Plane Transparent Surface

In diagram, XY is section of a plane transparent surface of a denser medium. A ray of light PQ strikes the surface at Q and goes along QR in denser medium. It is bent towards normal. This bending of ray of light when it travel in different medium, is called refraction. The surface is said to have refracted the light.

(i) Transparent surface: The plane surface which refracts light, is called transparent surface. In diagram, XY is the section of a plane transparent surface.

(ii) Point of incidence: The point Q on the boundary of two media where the incident ray strikes is called the point of incidence.

(iii) Normal: A perpendicular drawn at the point of incidence is called normal. In diagram, NQN' is the normal on surface XY.

(iv) Incident ray: The ray of light which strikes the transparent surface at the point of incidence is called incident ray. Here the ray PQ is the incident ray.

(v) Refracted ray: The ray of light on entering the second medium is called refracted ray. In Diagram, QR is the refracted ray.
(vi) **Angle of incidence:** The angle between the incident ray and the normal is called angle incidence ($\angle i$)

(vii) **Angle of refraction:** The angle between the refracted ray and the normal is called angle of refraction ($\angle r$)

(viii) **Plane of incidence:** The plane containing the normal and the incident ray is called plane of incidence. For the diagram, plane of paper is the plane of incidence.

(ix) **Plane of refraction:** The plane containing the normal and the refracted ray is called plane of refraction. For the diagram, plane of paper is the plane of refraction.

❖ **Characteristics of Refraction of Light**

The bending of light follows the following rules:

(i) **In going from a rarer to a denser medium:** A ray of light passing obliquely from an optically rarer medium to an optically denser medium, bends towards the normal. In this case the angle of refraction is always less than the angle of incidence.

![Diagram](chart1.png)

(ii) **In going from a denser to a rarer medium:** A ray of light passing obliquely from an optically denser medium to an optically rarer medium, bends away from the normal. In this case the angle of refraction is always greater than the angle of incidence.

![Diagram](chart2.png)

(iii) **When light is incident normally on a optically denser medium:** A ray of light passing normally, i.e., at right angles from one optical medium to another optical medium, does not bend or deviate from its path. In this case, angle of incidence and angle of refraction both are equal to zero.

![Diagram](chart3.png)

**ILLUSTRATION – 2**

Place a coin C at the bottom of an empty metallic vessel as shown in figure (a). Now slowly move away from the vessel until you reach a place where the coin just disappears. Now ask
somebody to slowly fill the vessel with water without disturbing the position of the coin. Maintain a steady gaze at the coin. The coin gradually begins to appear and can be seen completely from the same position of the eye after the level of water reaches a certain height.

As shown in figure (b), rays like CP and CQ cannot reach the eye, so the coin was not visible. A ray of light, CB coming from the lower end C of the coin passes from water in to air at a point B and gets refracted away from the normal in the direction BP'. Another ray of light, CD gets refracted in the direction DQ'. There refracted rays BP' and DQ' reach the eye of the observer, who sees the coin raised to C'. Thus the coin, which was not visible earlier, comes in to view. C' is the apparent position of the coin C, which appears to be raised up due to refraction of light.

- **Laws of Refraction of Light**

Refraction of light follows the following two laws:

**First Law:** The incident ray, the normal to the transparent surface at the point of incidence and the refracted ray, all lie in one and the same plane.

**Second Law:** The ratio of sine of the incidence angle (\(\angle i\)) to the sine of the refracted angle (\(\angle r\)) is constant and is called refractive index of the second medium with respect to the first medium. It is denoted by \(n\), i.e., \(\frac{\sin i}{\sin r} = n\)

Refractive index of second medium with respect to the first medium is denoted by \(n_1\). Thus, eqn. (i) can be written as \(n_1 = \frac{\sin i}{\sin r}\)

This law is called Snell’s law as it was stated by Prof. Willenbrod Snell (Dutch mathematician and astronomer).

- **Refractive index**

Light travels the fastest in vacuum with the highest speed of \(3 \times 10^8\) m s\(^{-1}\). In air, the speed of light is only marginally less, compared to that in vacuum. But for all practical purposes, we consider the speed of light in air equal to the speed of light in vacuum. However speed of light decreases in denser media like water, glass etc. It means when light goes from air to some other medium like water and glass, its speed decreases. The amount of change in the speed of light in a medium depends upon the property of the medium. This property is known as refractive index of the medium. Refractive index is a measure of how much the speed of light changes when it enters a medium from air.

- **Absolute Refractive index**

Absolute refractive index of a medium is defined as the ratio of the speed of light in vacuum or air to the speed of light in the medium. It is denoted by \(n\).
Refraction of Light

Then, \( n = \frac{\text{speed of light in air}}{\text{speed of light medium}} = \frac{c}{v} \); It has no unit.

Relative Refractive index

When light passes from medium 1 to another medium 2, the refractive index of medium 2 with respect to medium 1 is written as \( n_2/n_1 \) and is called relative refractive index. i.e., \( n = \frac{\sin i}{\sin r} \).

Values of Refractive Indices of Some Transparent media

<table>
<thead>
<tr>
<th>Names of Substance</th>
<th>Refractive Index</th>
<th>Names of Substance</th>
<th>Refractive Index</th>
</tr>
</thead>
<tbody>
<tr>
<td>Air</td>
<td>1.0003</td>
<td>Glycerine</td>
<td>1.47</td>
</tr>
<tr>
<td>Hydrogen</td>
<td>1.00013</td>
<td>Benzene</td>
<td>1.501</td>
</tr>
<tr>
<td>Carbon dioxide</td>
<td>1.00045</td>
<td>Crown glass</td>
<td>1.52</td>
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<td>Ice</td>
<td>1.31</td>
<td>Rock salt</td>
<td>1.54</td>
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<tr>
<td>Water</td>
<td>1.333</td>
<td>Carbon disulphide</td>
<td>1.63</td>
</tr>
<tr>
<td>Alcohol</td>
<td>1.36</td>
<td>Flint glass</td>
<td>1.66</td>
</tr>
<tr>
<td>Kerosene</td>
<td>1.44</td>
<td>Ruby</td>
<td>1.71</td>
</tr>
<tr>
<td>Carbon tetrachloride</td>
<td>1.46</td>
<td>Diamond</td>
<td>2.42</td>
</tr>
<tr>
<td>Turpentine oil</td>
<td>1.47</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Refraction through a Rectangular Glass Slab

Consider a rectangular glass slab ABCD. Ray PQ is incident on it on face AB at point Q, making angle \( \angle PQN = i \), called angle of incidence. It refracts in glass slab and goes along QR as refracted ray and becomes incident on face DC at point R from inside the slab.

Angle \( \angle RQN = r \) and is called angle of refraction. The ray emerges (comes out) from the slab along RS making \( \angle SRN = e \), called angle of emergence.

For refraction at Q (from air to glass),

According to Snell's law, \( n = \frac{\sin i}{\sin r} \) (i)

For refraction at R (from glass to air),

\[ \frac{1}{n} = \frac{\sin r}{\sin e} \] or \( n = \frac{\sin e}{\sin r} \) (ii)

From eqns. (i) and (ii), \( \sin i = \sin e \); i.e., \( i = e \)

Angle of incidence = angle of emergence

It means that in refraction through a rectangular glass slab the incident ray and emergent ray of light are parallel to each other.

Lateral Displacement

The perpendicular distance between the original path of incident ray and the emergent ray coming out of a glass slab is called lateral displacement of the emergent ray of light. In above diagram, LM represents lateral displacement for a glass slab.
Factors on which lateral displacement depends
(a) Lateral displacement is directly proportional to the thickness of glass slab.
(b) Lateral displacement is directly proportional to the incident angle.
(c) Lateral displacement is directly proportional to the refractive index of glass slab.
(d) Lateral displacement is inversely proportional to the wavelength of incident light.

ILLUSTRATION – 3
To verify the laws of refraction and determine the refractive index of the glass

Materials required
Rectangular glass slab, White sheet of drawing paper, Drawing board, Drawing Pins and all-purpose pins.

Procedure
Fix a plain sheet of paper on a drawing board with the help of drawing pins. Place a rectangular glass slab in the middle of the paper and draw its boundary with a sharp pencil. Fix two pins (P₁ and P₂) vertically along a straight line AB. Now look through the glass slab from the other side and fix two pins (P₃ and P₄) so that those pins and the images of the pins P₁ and P₂ are in a straight line (when seen through the glass slab). Remove the glass and all the pins. Mark the positions of the pins. Join the points P₁ and P₂ and extend the line to meet one face of the slab (Point B). Similarly, extend the line obtained by joining the points P₃ and P₄ to meet the other face of the slab (point C). Also the points B and C. Draw perpendiculars to the two faces of the slab at point B and point C. Measure and record the angle of incidence (i) and the angle of refraction (r). Repeat the experiment for different angles of incidence and determine the corresponding angles of refraction.

Calculations:
(i) Calculate the ratio sin i/sin r for all the observations. Calculate the average of all these values.
(ii) Plot a graph of sini vs sin r. Determine the slope of the plot.

Results: From the calculations, following results are obtained
(i) The ratio sini/sin r for all observations is constant.
(ii) The plot of sin i vs sin r is a straight line passing through the origin. The slope of sin i vs sin r plot is equal to the ratio sin i /sin r.

Conclusions:
(i) The constant value of the ratio sin i/sin r and the straight line plot between sin i and Sin r verify the first law of refraction or Snell’s law.
(ii) The incident ray, refracted ray and the normal, all lie in the same plane, i.e., plane of the Paper. This verifies the second law of refraction.
(iii) The average value of the sini/sinr ratio is equal to the refractive index of the glass of the slab.
(iv) The slope of sin i vs sin r plot is equal to the refractive index of the glass of the slab.
Spherical Lenses
A piece of transparent medium bounded by at least one spherical surface is called a spherical lens. Lenses are of two types:
(i) Convex or converging lenses.
(ii) Concave or diverging lenses

Convex Lens
A lens having both spherical surfaces or one spherical surface and other plane surface such that it is thick in the middle and thin at the edges is known as convex lens. There are three types of convex lenses:
(i) Bi-convex or double convex lens: It has both the surfaces convex as shown in figure (a).
(ii) Plano-convex lens: It has one surface plane and the other surface convex as shown in figure (b).
(iii) Concavo-convex lens: It has one surface concave and the other surface convex as shown in figure (c).

Concave Lens
A lens which is thicker at the edges and thin at the centre, i.e. curved inwards is known as Concave lens. Concave lenses are of three types:
(i) Double concave lens: It has both the surfaces concave as shown in figure (a).
(ii) Plano-concave lens: It has one surface plane and the other surface concave as shown in figure (b).
(iii) Convexo-concave lens: It has one surface convex and the other surface concave as shown figure (c).

Terms Associated with Spherical Lenses
(i) Aperture:
The diameter of the circular edge of the lens, is called the aperture of the lens. In diagram, AB is the aperture of the lens.
(ii) Centre of curvature:
The centre of curvature of a lens is defined as the centre of the spherical surface from which the lens has been cut. Thus, each surface of the lens is a part of a sphere. There will be two centers of curvature. In figures (a) and (b), C₁ and C₂ are the centers of curvature of the two lens surfaces.
(iii) Principal axis: An imaginary straight line passing through the two centers of curvature of two spherical surfaces of the lens (or through one centre of curvature of one spherical surface and normal to the other plane surface), is called the principal axis of the lens. For a plane concave or plane convex lens, the principal axis is a line, which is normal to the plane surface and passing through the centre of curvature of the curved surface.
(iv) **Optical centre:**
It is a point on the principal axis of the lens, such that a ray of light passing through it goes undeviated. In diagram, 'O' is optical centre of the lens.

(v) **First principal focus (F):**
The position of a point on the principal axis of a lens so that the rays of light starting from this point after passing through the lens travel parallel or appear to travel parallel to the principal axis is called first principal focus (F).
First principal focus (F) of a convex lens and a concave lens are shown in figure.

(vi) **Second Principal focus (F₂):**
The position of a point on the principal axis of a lens where a beam of light parallel to the principal axis meets or appears to meet after passing through the lens is called second principal focus (F₂).
Second principal focus (F₂) of a convex and a concave lens are shown in figure.

(vii) **Focal length:**
The distance between the optical centre of the lens and the principal focus (first or second) of the lens, is called focal length of the lens. It is represented by the symbol f. In diagram, OF = f.
(viii) **Focal plane:**
A vertical plane perpendicular to the principal axis, passing through the principal focus of the lens is called a focal plane. As shown in figure 1(a) and 1(b), the plane passing through the first principal focus is called first focal plane and that passing through the second principal focus is called second focal plane.

**ILLUSTRATIONS – 4**
Activity to determine the principal focus and rough focal length of a convex lens.
Fix a convex lens in a holder. Allow sunlight to fall on the convex lens. Now take a sheet of paper and adjust its position on the other side of the lens till a small but bright spot of light is formed on the paper as shown in figure. This spot of light is the principal focus of the given convex lens. Measure the distance of the paper from the lens. This distance is equal to the rough focal length of the lens.

**Image Formation in Lenses Using Ray Diagrams**
For geometrical construction of an image formed by a lens, any of three of following rays of light are used

- **Incident on the lens parallel to principal axis:** After refraction from the lens, it actually passes through second principal focus \(F_2\) (in case of a convex lens) or appears to come from the second principal focus \(F_2\) (in case of a concave lens).[Object at infinity, image at focus \(F_2\)]

- **Incident on the lens through first principal focus \(F_1\) (in case of a convex lens) or in direction of first principal focus \(F_1\) (in case of a concave lens):**
  After refraction from the lens, it goes parallel to the principal axis.
  [Object at focus \(F_1\), image at infinity]

- **Incident on the lens in direction of optical centre:**
  It passes undeviated through the lens.
  These special rays are very useful in drawing ray diagram in different cases.

- **Image Formation of Big Objects**
The object is divided into many points. Point to point images are obtain. By combining the point images, the image of the whole object is obtained. Real point images give real image and virtual point images give virtual image of the complete object.

**Note:** Since lenses used are supposed to have a small aperture, their surfaces can be taken as plane and their principal sections can be represented by a straight line.

**Example:** In figure, \(XY\) represent principal section of a convex lens. It is taken plane due to its small aperture.
AB is a real object having bottom A on the principal axis and top B upwards. Three special rays are shown coming from top B, incident on the lens and refracted as shown. They actually meet at a point B', which becomes real image of B. A' lies perpendicularly below B', on the principal axis. A' must represent image of bottom A of the object. A 'B' represents real image of complete object AB.

For small distances and sizes involved, the ray diagram can be drawn on same scale. For bigger distances and sizes, the diagram has to be drawn on a chosen scale.

### Sign Convention

**Description:** It is a convention which fixes the signs of different distances measured. The sign to be formed is the new Cartesian sign convention. It gives the following rules:

- The principal axis of the lens is taken along the X-axis of the rectangular coordinate system, and optical centre of the lens is taken as the origin.
- All distances are measured from the optical centre of the lens.
- The distances measured in the same direction as the direction of incident light, are taken as positive.
- The distances measured in the direction opposite to the direction of incident light, are taken as negative.
- Distances measured upward and perpendicular to the principal axis, are taken as positive.
- Distances measured downward and perpendicular to the principal axis, are taken as negative.

In short:

- Right → positive
- Left → negative
- Upward → positive, downward → negative.

### Lens Formula

The equation relating the object distance, the image distance and the focal length, is called the lens formula.

### Assumptions made

- The lens is thin.
- The lens has a small aperture.
- The object lies close to principal axis.
- The incident rays make small angles with the lens surface or the principal axis.

### Lens Formula for Convex Lens

The diagram shows the principal section of a convex lens L, forming a real and inverted image A'B' of a real and erect object AB. The object is beyond distance 2f, while the image is between Distance f and 2f.
Object distance (measured from C to A), \( CA = -u \) (object on the left of the lens)

Image distance (measured from C to \( A' \)), \( CA' = +v \) (image on right of the lens)

Focal length (measured from C to \( F_2 \)), \( CF_2 = +f \) (focus on right of the lens)

In similar triangles \( A'B'F_2 \) and \( CXF_2 \),
\[
\frac{A'B'}{CX} = \frac{F_2A'}{CF_2} = \frac{CA' - CF_2}{CF_2} = \frac{v-f}{f} \tag{i}
\]

In similar triangles \( A'B'C \) and \( ABC \),
\[
\frac{A'B'}{AB} = \frac{CA'}{AB} = \frac{v}{-u} \tag{ii}
\]

But since \( CX = AB \);
\[
\frac{A'B'}{AX} = \frac{A'B'}{AB} = \frac{v}{-u} \tag{ii}
\]

Hence, from eqns. (i) and (ii),
\[
\frac{v-f}{f} = \frac{v}{-u} \Rightarrow uv + uf = vf \Rightarrow uf - vf = uv
\]

Dividing by \( uvf \), we get
\[
\frac{1}{f} - \frac{1}{u} = \frac{1}{f} \quad \text{This is the required lens formula.}
\]

Lens Formula For Concave Lens

The diagram shows the principal section of a concave lens \( L \) forming a virtual and erect image \( A'B' \) of a real and erect object \( AB \). The object is beyond distance \( 2f \), while the image is between focus and optical centre on same side as the object. Here,

Object distance (measured from C to A), \( CA = -u \) (object on the left of the lens)

Image distance (measured from C to \( A' \)), \( CA' = -v \) (image on left of the lens)

Focal length (measured from C to \( F_2 \)), \( CF_2 = -f \) (focus on left of the lens)

In similar triangles \( A'B'F_2 \) and \( CXF_2 \),
\[
\frac{A'B'}{CX} = \frac{F_2A'}{CF_2} = \frac{CA' - CF_2}{CF_2} = \frac{-f - (-v)}{-f} = \frac{f - v}{f} \tag{i}
\]

In similar triangles \( A'B'C \) and \( ABC \),
\[
\frac{A'B'}{AB} = \frac{CA'}{AB} = \frac{-v}{-u} = \frac{v}{u} \tag{ii}
\]

But, since \( CX = AB \)

Hence, from eqns. (i) and (ii),
\[
\frac{f - u}{f} = \frac{v}{u} \Rightarrow uf - uv = vf \Rightarrow uf - vf = uv
\]

Dividing by \( uvf \), we get
\[
\frac{1}{v} - \frac{1}{u} = \frac{1}{f}
\]

This is the required lens formula.

Linear Magnification

The ratio of the size of the image as formed by refraction from the lens to the size of the object, is called linear magnification produced by the lens. It is represented by the symbol \( m \).

If \( I \) be the size of the image and \( O \) be the size of the object, then \( m = \frac{I}{O} \)
If we represent size of the object by $h_1$ and size of image by $h_2$ then, $I = h_2$ and $O = h_1$

Hence, $m = \frac{h_1}{h_2}$

**Expression:**

(i) For convex lens forming real image in figure (1).

$I = A'B' = -h_2$ (inverted image); $O = AB = +h_1$ (Erect object)

Then $m = \frac{-h_2}{h_1} = \frac{-A'B'}{AB}$ \(\text{In similar triangles A'B'C and ABC, } \frac{A'B'}{AB} = \frac{CA'}{CA}\)

Then, $m = -\frac{CA'}{CA} = -\frac{v}{u}$ i.e., $m = \frac{v}{u}$

(ii) For concave lens forming virtual image,

$I = A'B' = +h_2$ (erect image) $O = AB = +h_1$ (eject object); Then $m = \frac{-h_2}{h_1} = \frac{A'B'}{AB}$

In similar triangles A'B'C and ABC, $\frac{A'B'}{AB} = \frac{CA'}{CA}$; Then, $m = -\frac{CA'}{CA} = -\frac{v}{u}$ i.e., $m = \frac{v}{u}$

Hence, we concluded that the linear magnification produced by a lens is equal to the ratio of the image distance to the object distance with a plus sign.

**Note:** For mirror, $m = -\frac{v}{u}$. It is so because for an inverted image $v$ is negative in case of mirrors while it is positive in case of lenses.

The table below gives the position, nature and ray diagram for various objects, in convex and concave lens

<table>
<thead>
<tr>
<th>Position of Object</th>
<th>Position of Image</th>
<th>Nature of Image</th>
<th>Ray Diagram</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Convex lens</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(i) At $\infty$</td>
<td>At focus</td>
<td>Real inverted diminished</td>
<td><img src="image1" alt="Ray Diagram" /></td>
</tr>
<tr>
<td></td>
<td></td>
<td>$u$ is $-ve$ $v$ and $f$ are $+ve$</td>
<td></td>
</tr>
<tr>
<td>(ii) Beyond 2F</td>
<td>Between $F$ and 2F</td>
<td>Real, inverted diminished</td>
<td><img src="image2" alt="Ray Diagram" /></td>
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<tr>
<td></td>
<td></td>
<td>$u$ is $-ve$ $v$ and $f$ are $+ve$</td>
<td></td>
</tr>
<tr>
<td>(iii) At 2F</td>
<td>At 2F</td>
<td>Real, inverted size to size</td>
<td><img src="image3" alt="Ray Diagram" /></td>
</tr>
<tr>
<td></td>
<td></td>
<td>$u$ is $-ve$ $v$ and $f$ are $+ve$</td>
<td></td>
</tr>
<tr>
<td>Condition</td>
<td>Distance</td>
<td>Magnification</td>
<td>Image Description</td>
</tr>
<tr>
<td>------------------------------------------------</td>
<td>-------------------</td>
<td>-----------------</td>
<td>---------------------------------</td>
</tr>
<tr>
<td>(iv) Between F and 2F</td>
<td>Beyond 2F</td>
<td>Real, inverted enlarged</td>
<td><img src="image1.png" alt="Diagram" /></td>
</tr>
<tr>
<td>(v) At F</td>
<td>At ∞</td>
<td>Real, inverted enlarged</td>
<td><img src="image2.png" alt="Diagram" /></td>
</tr>
<tr>
<td>(vi) Between F and optical centre</td>
<td>On the same side of the lens</td>
<td>Vertical, erect enlarged</td>
<td><img src="image3.png" alt="Diagram" /></td>
</tr>
<tr>
<td>(vii) At ∞</td>
<td>At focus</td>
<td>Virtual, erect and diminished</td>
<td><img src="image4.png" alt="Diagram" /></td>
</tr>
<tr>
<td>(viii) At any position between ∞ and optical centre</td>
<td>Between F and optical centre</td>
<td>Virtual, erect and diminished</td>
<td><img src="image5.png" alt="Diagram" /></td>
</tr>
</tbody>
</table>

### Distinction between a Plane Glass Sheet, a Convex and a Concave Lens (without touching Surface)

The glass sheet is placed over a printed page and the virtual image of the print is seen. The magnification of the image is observed. Then make an idea of the magnification. If magnification is one, glass sheet is plane. If magnification is more than one, its a convex lens. If magnification is less than one, its a concave lens.

### Power of a Lens

A convex lens converges (brings closer) and a concave lens diverges (spreads) the light rays incident on it. More is the convergence or divergence produced by a lens, more powerful the lens is said to be. It is the capacity or the ability of a lens to deviate (converge or diverge) the path of rays passing through it. A lens producing more convergence or more divergence, is said to have more power. It is represented by the symbol P.
Relation of Power with Focal Length
A lens of less focal length focuses a parallel beam of light at near point. It produces more convergence or more divergence. It is said to have more power.

Hence power \( \propto \frac{1}{\text{focal length}} \) i.e., \( P \propto \frac{1}{f} \), We have, \( P = \frac{1}{f} \)

Units of power is dioptre (D). One dioptre is the power of a lens of focal length 1 m.

In general, \( P (\text{dioptre}) = \frac{1}{f (\text{metre})} = \frac{100}{f (\text{cm})} \)

Number of a Lens
(i) A convex lens of focal length +50 cm (+0.5 m), has power +2 dioptre. Its number is +2.
(ii) A concave lens of focal length -20 cm (-0.2 m), has power -5 dioptre. Its number is -5.

Focal Length and Power of a Lens Combination
The power of the combination of a number of thin lenses placed in contact is equal to the algebraic sum of the powers of the individual lenses.

For a Two Lens Combination
Let lenses \( L_1 \) and \( L_2 \) have focal lengths \( f_1 \) and \( f_2 \) and powers \( P_1 \) and \( P_2 \) respectively. They are very thin so that their optical centers \( C_1 \) and \( C_2 \) lie very close. Let for the combination, focal length = \( F \) Power = \( P \) Lens \( L_1 \), forms real image of point object \( O \) at point \( I' \). \( I' \) acts as virtual object for lens \( L_2 \), which makes final real image at \( I \).

For lens \( L_1 \), \( C_1 O = u, C_1 I' = v' \)

For lens \( L_2 \), \( C_2 I' = v', C_2 I = +v \)

From lens formula, \( \frac{1}{v'} - \frac{1}{u} = \frac{1}{f_1} \) \( \frac{1}{v'} - \frac{1}{u} = \frac{1}{f_2} \)

Adding equations (i) and (ii)
\( \frac{1}{v} - \frac{1}{u} = \frac{1}{f} \)

For the combination, \( \frac{1}{v} - \frac{1}{u} = \frac{1}{f} \)

Hence, from equation (iii) and (iv), \( \frac{1}{f} = \frac{1}{f_1} + \frac{1}{f_2} \) or \( P = P_1 + P_2 \)

Note: For a number of thin lenses having very close optical centers \( P = P_1 + P_2 + \ldots + P_n \) or \( P = \sum_{n=1}^{n} P \)

APPLICATIONS OF SPHERICAL LENSES
✓ A convex lens is frequently used as a magnifying glass e.g., a watch maker, student in the laboratory.
✓ Lenses are also used in a camera to form the image of an object on the screen or photographic film.
In a microscope and a telescope for viewing near and distance objects and in other optical instruments.

A convex lens is usually used to get rid of hypermetropia.

A concave lens of suitable focal length is used to cure myopia

Used in a photocopies, projector, etc.

**Interesting facts.**

- **Mirage:** Sometimes in deserts, an inverted image of a tree is seen, which gives a false impression of water under the tree. This is called a mirage. A mirage is an optical illusion caused by refraction.

![Mirage on the hot road](image)

- **Looming:**

  Because of the enhanced bending effect, an object floating on the water appears to the suspended in the air. This optical illusion in known as looming.

- **Superior sunset Mirage:**

  ![Superior sunset Mirage](image)

---

### Solved Examples

1. The speed of light in air is $3 \times 10^8$ ms$^{-1}$ and the speed of light in water is $2.26 \times 10^8$ ms$^{-1}$. Find the refractive index of water.

   **Sol:**

   Given, $c = 3 \times 10^8$ m s$^{-1}$, $v = 2.26 \times 10^8$ m s$^{-1}$
Using \( n = \frac{c}{v} \), we have \( n = \frac{3 \times 10^8 \text{ ms}^{-1}}{2.26 \times 10^8 \text{ ms}^{-1}} = 1.33 \)

2. Light travels from a rarer medium 1 to a denser medium 2. The angle of incidence and refraction are respectively 45° and 30°. Calculate the refractive index of first medium with respect to the first medium.

**Sol:**

Given angle of incidence, \( i = 45° \) angle of refraction, \( r = 30° \)

From relation, \( \frac{\sin i}{\sin r} = \frac{\sin 45°}{\sin 30°} = \frac{1}{\sqrt{2}} \)

3. In the above, calculate the refractive index of first medium with respect to second medium.

**Sol:**

From relation \( \frac{1}{n_2} = \frac{1}{n_1} \); Putting values, we get \( \frac{1}{n_2} = \frac{1}{\sqrt{2}} \) \( \rightarrow \) (i)

Multiplying and dividing equation by \( \sqrt{2} \), \( \frac{1}{n_2} = \frac{1}{\sqrt{2}} \times \frac{\sqrt{2}}{\sqrt{2}} = \frac{\sqrt{2}}{2} = \frac{1.414}{2} = 0.707 \)

4. A concave lens of focal length 20 cm form an image at a distance of 10 cm from the lens. What is the distance of the object from the lens? Also draw ray diagram.

**Sol:**

Here, \( f = -20 \text{ cm (sign convention)} \)

\( u = -10 \text{ cm (image formed by concave lens is virtual)} \)

Using, \( \frac{1}{f} = \frac{1}{u} + \frac{1}{v} \) we have \( \frac{1}{u} = - \frac{1}{20} + \frac{1}{10} = \frac{1}{20} \)

or \( u = -20 \text{ cm} \).

5. What will be the focal length of a lens whose power is given as +2.0 D?

**Sol:**

Here, \( P = 2D \), using \( P = \frac{100}{f \text{ (in cm)}} \), we get; \( \frac{1}{P} = \frac{1}{2} = 0.5 \text{ cm} \)

6. What is the power of a convex lens of focal length 40 cm?

**Sol:**

Here, \( f = 40 \text{ cm} \), using, \( P = \frac{100}{f \text{ (in cm)}} \) we have \( P = \frac{100}{40} = +2.5 \text{D} \)

7. Two lenses of one focal length 20 cm (convex lens) and another of focal length -15 cm (concave lens) are placed in contact. What is the focal length and power of the combination?

**Sol:**

Here, \( f_1 = +20 \text{ cm} = +0.2 \text{ m}; f_2 = -15 \text{ cm} = -0.15 \text{ cm}, F = ?, P = ? \)

From relation, \( \frac{1}{F} = \frac{1}{f_1} + \frac{1}{f_2} \); Putting values, we get \( \frac{1}{F} = \frac{1}{0.2} + \frac{1}{-0.15} = \frac{3 - 4}{0.6} = -\frac{1}{0.6} \) or \( F = -0.6 \text{ m} \)

From relation, \( P = \frac{1}{F} = -\frac{1}{0.6} = -1.67 \text{ D} \), \( P = -1.67 \text{D} \)

8. Two lenses of power +3.5 D and -2.5 D are placed in contact. Find the power and focal length of the lens combination.

**Sol:**

When lenses are placed in contact then we have \( P = P_1 P_2 + …. \) And \( \frac{1}{f} = \frac{1}{f_1} + \frac{1}{f_2} + …. \)
Therefore we have \( P = + 3.5 - 2.5 = +1 \) D; And \( f = \frac{1}{P} = \frac{1}{1} = 1 \) m

The combination behaves as a convex lens.

9. **An object of size 3 cm is placed at a distance of 15 cm from a convex lens of focal length 10 cm. Calculate the distance and size of the images so formed. What will be the nature of the image?**

**Sol.**

Given \( O = 3 \) cm, \( u = -15 \) cm, \( f = +10 \) cm, \( v = ? \) And \( I = ? \)

Using lens formula we have

\[
\frac{1}{v} - \frac{1}{u} = \frac{1}{f} \quad \text{or} \quad \frac{1}{v} - \frac{1}{f} = \frac{1}{u} \quad \Rightarrow \quad \frac{1}{10} - \frac{1}{15} = \frac{5}{150} = \frac{1}{30}
\]

Therefore \( v = 30 \) cm; Also \( m = \frac{v}{O} = \frac{v}{u} \); therefore \( m = \frac{I}{O} = \frac{30}{-15} \) solving we have

\( I = -6 \) cm; The image is real, inverted and magnified.

10. **A concave lens of focal length 15 cm forms an image 10 cm from the lens. How far is the object placed from the lens? Also find the magnification produced by the lens.**

**Sol.**

Given \( f = -15 \) cm, \( v = -10 \) cm, \( u = ? \)

By lens formula we have

\[
\frac{1}{v} - \frac{1}{u} = \frac{1}{f} \quad \Rightarrow \quad \frac{1}{v} - \frac{1}{15} = \frac{1}{-10}
\]

Therefore

\[
u = \frac{15 \times 10}{10 - 15} = -30 \text{ cm}
\]

The object is placed at a distance of 30 cm from the lens.

Magnification \( m = \frac{v}{u} = \frac{-10}{-30} = \frac{1}{3} = +0.33 \)

The positive sign shows that the image is erect and virtual. The image is smaller than the object.

11. **A 2 cm tall object is placed perpendicular to the principal axis of a convex lens of focal length 10 cm. The distance of the object from the lens is 15 cm. Find the nature, position and size of the image. Also find its magnification.**

**Sol.**

Given \( h = 2 \) cm, \( u = -15 \) cm, \( f = +10 \) cm, \( v = ?, \) nature = ?, \( h' = ? \)

By lens formula we have

\[
\frac{1}{v} - \frac{1}{u} = \frac{1}{f} \quad \Rightarrow \quad \frac{1}{v} + \frac{1}{10} + \frac{1}{-15} = \frac{1}{30}
\]

Therefore \( v = +30 \) cm.

The positive sign shown that the image is formed on the other side of the lens. It is real and inverted

Also Magnification \( m = \frac{h'}{h} = \frac{v}{u} \); Therefore \( h' = h \times \frac{v}{u} = 2 \times \frac{30}{-15} = -4 \) cm

Also magnification \( m = \frac{v}{u} = \frac{+30}{-15} = -2 \)

The negative sign shows that the image is real and inverted.

12. **A compound lens is made of two lenses in contact having powers +12.5 D and -2.5 D. An object is placed at 15 cm from this compound lens. Find the position and nature of the image formed.**

**Sol.**

\( P_1 = 12.5 \) D, \( P_2 = -2.5 \) D.

Equivalent power; \( P = P_1 + P_2 = 12.5 - 2.5 = 10 \) D.
Refraction of Light

Focal length equivalent \(= \frac{100}{10} \text{ cm} = 10 \text{ cm}\)

Given, \(u = -15 \text{ cm}\)

Using, \(\frac{1}{f} = \frac{1}{v} - \frac{1}{u}\) we get \(\frac{1}{v} = \frac{1}{f} + \frac{1}{u} = \frac{1}{10} + \frac{1}{-15} = \frac{5}{150} v = \frac{150}{5} = 30 \text{ cm}\)

Image is real and is at a distance 30 cm on other side of the object from the convex lens.

**VERY SHORT ANSWER QUESTIONS**

1. What are the conditions for no refraction of light?
2. What is the range of wavelength of visible light? Which color has the largest wavelength and which one has the shortest wavelength?
3. A coin in a glass beaker appears to rise as the beaker is slowly filled with water. Why?
4. What is lateral magnification produced by a lens? How is it related to object distance and image distance?
5. A tank of water is 4 m deep. How deep does it appear when seen normally?
6. When is magnification positive or negative?
7. What is meant by a lens of power +1 D?
8. A spherical mirror and a thin spherical lens have a focal length of -15 cm each. What type of lens and the mirror are referred here?

**SHORT ANSWER TYPE QUESTIONS**

9. A convex lens forms a real and inverted image of a needle at a distance of 50 cm from it. Where is the needle placed in front of the convex lens if the image is equal to the size of the object? Also, find the power of the lens.
10. One half of a convex lens is covered with a black paper. Will this lens produce a complete image of the object? Verify your answer experimentally. Explain you observations.
11. An object 5 cm in length is held 25 cm away from a converging lens of focal length 10 cm. Draw the ray diagram and find the position, size and he nature of the image formed.
12. A concave of focal length 15 cm forms an image 10 cm from the lens. How far is the object placed from the lens? Draw he ray diagram?
13. Find the focal length of a lens of power -2.0 D. What type of lens is this?
14. A doctor has prescribed a corrective lens of power +1.5 D. Find the focal length of the lens. Is the prescribed lens diverging or converging?
15. What is a lens? Distinguish between a convex and concave lens. Which of the two is a converging lens: Convex or concave lens?
16. a) Which of the two lens is called as diverging lens? Why? Explain with the help of neat labeled diagram.
   b) Define principal focus.
17. State and explain the new cartesian sign convention for spherical lens.
18. A convex lens of focal length 10 cm is placed at a distance of 12 cm from a wall. How far from the lens should an object be placed so as to form its real image on the wall?

**LONG ANSWER QUESTIONS**

19. (i) If \(f = +0.5 \text{ m}\), what is the power of the lens?
(ii) The radii of curvature of the faces of a double convex lens are 9 cm and 15 cm. Its focal length is 12 cm. What is the refractive index of glass?
(iii) A convex lens has 20 cm focal length in air. What is the focal length in water? (Refractive index of air–water = 1.33, refractive index of air–glass = 1.5).

20. An object is placed 30 cm from a concave lens. The focal length of the concave lens is 12 cm. Find the position of the image with the help of diagram.

21. The object is placed in front of a concave lens of focal length 20 cm. Magnification is found to be \(\frac{1}{2}\). Find the location of the object.

22. In the given figure, a 2 cm high object is placed at a distance of 16 cm from a convex lens. The focal length of the lens is 12 cm. Find the
(a) Position of the image
(b) Size of the image
(c) Nature of the image

23. In the given figure, a 3 cm high object is placed at a distance of 30 cm from a concave lens of focal length 15 cm. Find the
(a) Position of the image
(b) Size of the image
(c) Nature of the image

HIGH ORDER THINKING SKILLS

24. A virtual image cannot be focused on a screen. Yet when we see a virtual image, we obviously bring it to the screen that is the retina of our eyes. Is this a contradiction?

25. A concave mirror and a convex lens are held in water. What changes, if any, do you expect in their focal length?

26. What happens to the image formed by a convex lens if its lower part is blackened?

27. It is possible for a lens to act as a convergent lens in one medium and a divergent lens in another?

28. Which of the following diagrams shows the ray of light refracted correctly?

29. How is the reflection of light ray from a plane mirror different from the refraction of light ray as it enters a block of glass?

30. The following table gives refractive indices of a few media:

<table>
<thead>
<tr>
<th>Medium</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Refractive index</td>
<td>1.33</td>
<td>1.52</td>
<td>1.54</td>
<td>1.71</td>
<td>2.42</td>
</tr>
</tbody>
</table>

Use this table to give an example of:
(i) a medium pair so that light speeds up when it goes from one these medium to another
Refraction of Light

(ii) a medium pair so that light slows down when it goes from one of these medium to another.

31. A student did an experiment with a convex lens. He put an object at different distances 25 cm, 30 cm, 40 cm, 60 cm and 120 cm from the lens. In each case he measured the distance of the image from the lens. His results were 100 cm, 24 cm, 60 cm, 30 cm and 40 cm, respectively. Unfortunately his results are written in wrong order.
   (a) Rewrite the image distance in the correct order.
   (b) What would be the image distance if the object distance was 90 cm?
   (c) Which of the object distances gives the biggest image?
   (d) What is the focal length of this lens?

32. An object 50 cm tall is placed on the principal axis of a convex lens. Its 20 cm tall image is formed on the screen placed at a distance of 10 cm from the lens. Calculate the focal length of the lens.

TRUE (or) FALSE

33. A ray parallel to the principal axis, after reflection, will pass through the principal focus.
34. Light travels faster in glass than in air.
35. The degree of convergence or divergence of light rays achieved by a lens is expressed in terms of its power.
36. Concave lenses are used mainly in spectacles for the correction of short sightedness.
37. A ray of light passing through the optical centre of a lens does not suffer any deviation.
38. The lateral displacement during refraction does not depend on wavelength of the light.
39. Air has the highest optical density.
40. An opaque material cannot be used to make a lens.
41. One dioptre is equal to 1 m.
42. Focal length of convex lens is always positive.

FILL IN THE BLANKS

43. To construct a ray diagram, you need at least______ whose path(s) after refraction through the lens are known.
44. The principal axis is also called______ of the lens.
45. The power of a lens whose focal length is one metre is ______ dioptre.
46. The scattering of light depends inversely upon the fourth power of the______ of light.
47. The power of a convex lens is______ and that of a concave lens is______.
48. The relationship \( \frac{1}{f} = \frac{1}{v} - \frac{1}{u} \) is called the______ formula.
49. No refraction occurs when light incident______ on a boundary of two medium.
50. Light emerges from rectangular glass slab in a direction______ to that in which it entered the glass slab.
51. Oval shape of sun at sunrise and sunset is due to______ of light.
52. The largest value of refractive index is 2.42 for______.

MULTIPLE CHOICE TYPE QUESTIONS

53. A concave lens of focal length forms an image which is n times the size of the object. The distance of the object from the lens is

   1) \((1-n)f\)  
   2) \((1+n)f\)  
   3) \(\left(\frac{1+n}{n}\right)f\)  
   4) \(\left(\frac{1-n}{n}\right)f\)
54. A lens behaves as a converging lens in air and a diverging lens in water. The refractive index of the material is
   1) Equal to unity  
   2) Equal to 1.33  
   3) Between unity and 1.33  
   4) Greater than 1.33

55. A thin convex lens of focal length 10 cm and a thin concave lens of focal length 26.2 cm are in contact. The combination acts as
   1) Concave lens of focal length 16.4 cm  
   2) Convex lens of focal length 16.2 cm  
   3) Concave or convex lens depends upon the material of lenses  
   4) None

56. A thin equiconvex lens has focal length 10 cm, refractive index 1.5. One of its faces is now silvered and for an object placed at a distance ‘u’ in front of it, the image coincides with the object. The value of ‘u’ is
   1) 10 cm  
   2) 5 cm  
   3) 20 cm  
   4) 15 cm

57. A convex lens A of focal length 20 cm and a concave lens B of focal length 5 cm are kept along the same axis with a distance d between them. If a parallel beam of light falling on A leaves B as a parallel beam, then the distance d in cm will be
   1) 125  
   2) 15  
   3) 30  
   4) 50

58. Bending of rays light, when it enters obliquely from one medium to other is called
   1) Dispersion  
   2) Interference  
   3) Reflection  
   4) Refraction

59. For light going from air to water: \( \frac{n_a}{n_w} = \frac{4}{3} \). Then \( n_a \) has value
   1) 1  
   2) 3/4  
   3) 16/9  
   4) 3/2

60. A ray of light passes undeviated through a point on the principal axis. The point is
   1) Optical centre  
   2) No where  
   3) Focus  
   4) Centre of curvature

61. For studying refraction through a lens, we keep the lens with its refracting surface towards
   1) Up  
   2) Down  
   3) Right  
   4) Left

62. Which one of the following materials cannot be used to make a lens?
   1) Water  
   2) Glass  
   3) Plastic  
   4) Clay

63. Which of the following lenses would you prefer to use while reading small letters found in a dictionary?
   1) Convex lens of focal length 50 cm  
   2) A concave lens of focal length 50 cm  
   3) A convex lens of focal length 5 cm  
   4) A concave lens of focal length 5 cm

64. Light travelling from a denser medium to a rarer medium along a normal to the boundary:
   1) Is refracted towards the normal  
   2) Is refracted away from the normal  
   3) Goes along the boundary  
   4) Is not refracted.

65. A ray of light passes from glass into air. The angle of refraction will be:
   1) Equal to the angle of incidence  
   2) Greater than the angle of incidence  
   3) Smaller than the angle of incidence  
   4) 45°

66. A ray of light travelling in air goes into water. The angle of refraction will be:
   1) 90°  
   2) Smaller than the angle of incidence  
   3) Equal to the angle of incidence  
   4) Greater than the angle of incidence

67. The refractive index of glass of light going from air to glass is \( \frac{3}{2} \). The refractive index for light going from glass to air will be:
The refractive indices of four media A, B, C, and D are 1.44, 1.52, 1.65, and 1.36 respectively. When light travelling in air is incident in these media at equal angles, the angle of refraction will be the minimum:

1) in medium A  
2) in medium B  
3) in medium C  
4) in medium D

The speed of light in substance X is $1.25 \times 10^8$ m/s and that in air is $3 \times 10^8$ m/s. The refractive index of this substance will be:

1) 2.4  
2) 0.4  
3) 4.2  
4) 3.75

A convex lens has a focal length of 10 cm. At which of the following position should an object be placed so that this convex lens may act as a magnifying glass?

1) 15 cm  
2) 7 cm  
3) 20 cm  
4) 25 cm

Which one of the following materials cannot be used to make a lens?

1) Water  
2) Glass  
3) Plastic  
4) Clay

A small bulb is placed at the focal point of a converging lens. When the bulb is switched on, the lens produces:

1) a convergent beam of light  
2) a divergent beam of light  
3) a parallel beam of light  
4) a patch of coloured light

An illuminated object is placed a distance of 20 cm from a converging lens of focal length 15 cm. The image obtained on the screen is:

1) upright and magnified  
2) inverted and magnified  
3) inverted and diminished  
4) upright and diminished

An object is placed between $f$ and $2f$ of a convex lens. Which of the following statements correctly describes its image?

1) real, larger than the object  
2) erect, smaller than the object  
3) inverted, same size as object  
4) virtual, larger than the object.

VERY SHORT ANSWER QUESTIONS
1. What is refractive index?
2. If refractive index of glass with respect to air is 3/2, what is the refractive index of air with respect to glass?
3. What is meant by optical centre of a lens?
4. What is the difference between a real image and a virtual image?
5. For the same slab of glass and the same angle of incidence, the lateral displacement for violet light is more than the red light. Generalize this observation in terms of effect of wavelength of light on the lateral displacement.
6. Does velocity of light change when it goes from one medium to another?
7. Where should an object be placed so that a real and inverted image of the same size is obtained using a convex lens?
8. For what position of the object will a convex lens form a virtual and erect image?
9. A ray of light travelling in air enters obliquely into water. Does the light ray bend towards the normal or away from the normal? Why?

10. Light enters from air to glass having refractive index 1.5. What is the speed of light in glass? The speed of light in vacuum is $3 \times 10^8$ m/s.

11. Give the medium having highest optical density. Also, give the medium with lowest optical density.

12. You are given kerosene, turpentine and water. In which of these does the light travels fastest?

13. The refractive index of diamond is 2.42. What is the meaning of this statement?

14. Define 1 dioptr of power of lens.

15. Find the power of a concave lens of focal length 2 m.

16. Define the laws of refraction.

17. How does the speed light in glass change on increasing the wavelength of light.

18. a) explain with the help of a diagram, why the convex is also called as a converging lens. 
   b) Define the principal focus of a concave lens and focal length of a lens.

**LONG ANSWER QUESTIONS**

19. A ray of light travelling in air falls on the surface of a rectangular slab of a material whose refractive index is 1.2. If the incident ray makes an angle of 37° with the normal (sin 37° = 3/5), find the angle made by the refracted ray with the normal.

20. A light of wavelength 500 nm in air enters a glass block of refractive index 1.5. Find (a) speed (b) Frequency (c) Wavelength of light in glass. Velocity of light in air is $3 \times 10^8$ m/s.

21. An object placed in front of a diverging mirror at a distance of 30 cm, forms a virtual and erect image which is 1/5 of the size of the object. Calculate: 
   (i) The position of the image 
   (ii) The focal length of the diverging mirror.

22. An object of size of 7.0 cm is placed 27 cm in front of concave mirror of focal length 18 cm. At what distance from the mirror, should a screen be place, so that a sharp focused image can be obtained? Find the size and nature of the image.

23. A convex lens is made of glass of refractive index 1.5. If radius of curvature of each of its two surfaces is 20 cm, find the ratio of the power of the lens, when placed in air to its power when immersed inside a liquid of refractive index 1.25.

**HIGH ORDER THINKING SKILLS**

24. How will you decide whether a given piece of glass is a convex lens, concave lens or a plane glass plate?

25. A concave lens made of a material of refractive index $n_1$ is kept in a medium of refractive index $n_2$. A parallel beam of light is incident on the lens. Complete the path of rays of light emerging from the concave lens if (i) $n_1 > n_2$ (ii) $n_1 = n_2$ (iii) $n_1 < n_2$.

26. A vertical ray of light strikes the horizontal surface of some water: 
   (a) What is the angle of incidence? 
   (b) What is the angle of refraction?

27. How does the light have to enter the glass: 
   (a) to produce a large amount of bending? 
   (b) for no refraction to happen?
28. Refractive indices of four media A, B, C and D are given below:

<table>
<thead>
<tr>
<th>Medium</th>
<th>Refractive index</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>1.33</td>
</tr>
<tr>
<td>B</td>
<td>1.44</td>
</tr>
<tr>
<td>C</td>
<td>1.52</td>
</tr>
<tr>
<td>D</td>
<td>1.65</td>
</tr>
</tbody>
</table>

In which of these four media is the speed of light
(i) maximum, and (ii) minimum?

29. A magnifying lens has a focal length of 100 mm. An object whose size is 16 mm is placed at some distance from the lens so that an image is formed at a distance of 25 cm in front of the lens.

(a) What is the distance between the object and the lens?
(b) Where should the object be placed if the image is to form at infinity?

30. A lens forms a real image 3 cm high of an object 1 cm high. If the separation of object and image is 15 cm, find the focal length of the lens.

31. When an object is placed 10 cm in front of lens A, the image is real, inverted, magnified and formed at a great distance. When the same object is placed 10 cm in front of lens B, the image formed is real, inverted and same size as the object.

(a) What is the focal length of lens A?
(b) What is the focal length of lens B?
(c) What is the nature of lens A?
(d) What is the nature of lens B?

32. A camera fitted with a lens of focal length 50 mm is being used to photograph a flower that is 5 cm in diameter. The flower is placed 20 cm in front of the camera lens.

(a) At what distance from the film should the lens be adjusted to obtain a sharp image of the flower?
(b) What would be the diameter of the image of the flower on the film?
(c) What is the nature of camera lens?

33. An object is 2 m from a lens which forms an erect image one-fourth (exactly) the size of the object. Determine the focal of the lens. What type of lens is this?

34. An image formed on a screen is three the size of the object. The object and screen are 80 cm apart when the image is sharply focused.

(a) State which type of lens is used.
(b) Calculate focal length of the lens.

35. The optical prescription for a pair of spectacles is:
Right eye: – 3.50 D     Left eye: – 4.00 D

(a) Are these lenses thinner at the middle or at the edges?
(b) Which lens has a greater focal length? (c) Which is the weaker eye?

36. A person got his eyes tested by an optician. The prescription for the spectacle lenses to be made reads:
Left eye: + 2.50 D     Right eye: + 2.00 D

(a) State whether these lenses are thicker in the middle or at the edges.
(b) Which lens bends the light rays more strongly?
(c) State whether these spectacle lenses will converge light rays or diverge light rays.
**TRUE (or) FALSE**

37. When light travels from air into water, its speed increases.
38. Regular reflection is also called total internal reflection.
39. A real image is formed by a concave lens when the object is placed at infinity.
40. Concave lens are used as reflectors in lamps.
41. For image magnification one needs at least two convex lens.
42. If two mirrors are inclined to each other at 90°, the image seen may be four.
43. A ray passing through optical centre proceeds undeviated through the lens.
44. According to new sign convention, all distances are measured from poles.
45. The power of a lens can be measured in watt.
46. In optical instrument, the lenses are used to form images by dispersion.
47. The unit of refractive index is dioptre.

**FILL IN THE BLANKS**

48. A convex lens of smaller focal length has ______ power.
49. A tank appears to be 3 m deep only, then the actual depth of tank is ______.
50. The effective width of a lens from which refraction takes place is called its______.
51. A lens having one curved surface bulged outwards and the other a plane surface is called______ lens.
52. Air is optically______ than water or glass.
53. The refractive index of vacuum is taken as______.
54. The instrument that can directly measure the power of a lens is called______.
55. A medium with higher refractive index is said to be______.
56. The critical angle for a material of refractive index √2 is______.
57. ______ of lens is defined as the ability of the lens to converge a beam of light falling on the lens.
58. The power of plano convex lens, is ______ when radius of curved surface is 15 cm and n is 1.5.

**MULTIPLE CHOICE TYPE QUESTIONS**

59. We put a glass piece on a printed page. Image of prints on the page has same size. The piece is a
   1) concave lens  2) prism  3) glass slab  4) convex lens
60. The power of a glass slab is
   1) zero  2) infinite  3) less  4) more
61. In a lens combination of thin lenses in contact, for obtaining the power of the combination
   power of individual lens are algebraically
   1) multiplied  2) divided  3) added  4) subtracted
62. A thin lens has focal length f, and its aperture has diameter d. It forms an image of intensity I.
   Now, the central part of the aperture up to diameter d/2 is blocked by an opaque paper. The
   focal length and image intensity will change to
   1) f/2 and I/2  2) f and I/4  3) 3f/4 and I/2  4) f and 3I/4
63. A convergent beam is incident on a concave lens as shown in figure. Which of the
   following statements is not correct?
   1) The image formed is real  2) The image formed is virtual  3) The image formed is erect
   4) The image formed is magnified
64. A convex lens is made of two transparent materials A and B. A ray of light is incident on the
   lens from a point object. We will see
   1) four images  2) two images  3) six images  4) None
65. When white light passes through a dispersive medium, it breaks up into various colors. Which of the following is true?
1) Velocity of light for violet is greater than the velocity of light for red color
2) Velocity of light for violet is less than the velocity of light for red color
3) Velocity of light is the same for all color
4) Velocity of light is different for different colors

66. Focal length of a lens for red color is
1) Same as that for violet
2) greater than that for violet
3) Lesser than that for violet
4) None

67. Even in absolutely clear water, a diver cannot see very clearly
1) because rays of light get diffused
2) because velocity of light is reduced in water
3) because of ray light passing through the water makes it turbid
4) because the focal length of the eye lens in water gets changed and the image is no longer focused sharply on the retina.

68. The speed of light of incidence
3 \times 10^8 \text{ cm/s} \quad 2) 3 \times 10^8 \text{ mm/s} \quad 3) 3 \times 10^8 \text{ km/s} \quad 4) 3 \times 10^8 \text{ m/s}

69. When a ray of light travelling in glass enters into water obliquely:
1) it is refracted towards the normal
2) it is not refracted at all
3) it goes along the normal
4) it is refracted away from the normal

70. A ray of light travelling in waterfalls at right angles to the boundary of a parallel-sided glass block. The ray of light:
1) is refracted towards the normal
2) is refracted away from the normal
3) does not get refracted
4) is refracted along the same path.

71. The refractive indexes of four substances P, Q, R and S are 1.77, 1.50, 2.42 and 1.31 respectively. When light travelling in air is incident on these substances at equal angles, the angle of refraction will be the maximum in:
1) substance P
2) substance Q
3) substance R
4) substance S

72. The refractive index of water is:
1) 1.33
2) 1.50
3) 2.42
4) 1.36

73. The refractive index of water with respect to air \frac{4}{3}. The refractive index of air with respect to water will be:
1) 1.75
2) 0.50
3) 0.75
4) 0.25

74. In order to obtain a real image twice the size of the object with a convex lens of focal 15 cm, the object distance should be:
1) more than 5 cm but less than 10 cm
2) more than 10 cm but less than 15 cm
3) more than 15 cm but less than 30 cm
4) more than 30 cm but less than 60 cm

75. A converging lens is used to produce an image of object on a screen. What change is needed for the image to be formed nearer to the lens?
1) increase the focal of the lens
2) insert a diverging lens between the lens and the screen
3) increase the distance of the object from the lens
4) move the object closer to the lens
76. A convex lens of focal length 8 cm forms a real image of the same size as the object. The distance between object and its image will be:
1) 8 cm  
2) 16 cm  
3) 24 cm  
4) 32 cm

77. A convex, erect and magnified image of an object is to be obtained with a convex lens. For this purpose, the object should be placed:
1) between 2F and infinity  
2) between F and optical centre  
3) between F and 2F  
4) at F

78. A burning candle whose flame is 1.5 cm tall is placed at a certain distance in front of a convex lens. An image of candle flame is received on a white screen kept behind the lens. The image of flame also measures 1.5 cm. If f is the focal length of convex lens, the candle is placed:
1) at f  
2) between f and 2f  
3) at 2f  
4) beyond 2f

**Very Short Answer Questions**

1. What type of lens’s behavior will an air bubble inside water show?

2. For the same angle of incidence, the angle of refraction in three media A, B and C are 15°, 25° and 35° respectively. In which medium is the velocity of light minimum? [Delhi 2006]

3. The refractive index of diamond is 2.42. What is the meaning of this statement in relation to the speed of light? [Delhi 2009]

4. Why does a ray of light bend when it travels from one medium into another? [Delhi 2009]

5. Draw the given diagram in your answer book and complete it for the path of ray light beyond the lens.

6. Draw ray diagrams to show the formation of the image of an object by a concave lens, when the object is placed
   (i) at infinity and (ii) between infinity and the optical centre of the lens. [CBSE March 2012]

7. How will you distinguish between a convex and a concave lens without touching them? [CBSE March 2011]

8. (a) What happens to a ray of light when it travels from one medium to another having equal refractive indices?
   (b) State the cause of refraction of light. [CBSE March 2011]

9. (a) Draw a labeled diagram to show the refraction of light through a glass slab.
   (b) Refractive index of the diamond is 2.42, what does it mean? [CBSE March 2011]

**Long Answer Questions**

10. Draw a labeled ray diagram to locate the image of an object formed by a convex lens of focal length 20 cm when the object is placed 30 cm away from the lens. [AISSE 2006]

11. What is lateral shift? Explain with the help of a diagram.

12. Draw a ray diagram in each of the following cases to show the formation of image, when the object is placed
(i) between optical centre and principal focus of a convex lens.
(ii) between F and 2F of a convex lens.
(iii) At 2F of convex lens.
What can you say about sign and value of linear magnification ratio in, (i) and (ii) above?

13. A thin converging lens forms a:
   (i) Real magnified image
   (ii) Virtual magnified image of an object placed in front of it
   (a) Write the positions of the objects in each case.
   (b) Draw labeled ray diagrams to show the image formation in each case.
   (c) How will the following be affected on cutting this lens into two halves along the principal axis?
   (i) Focal length,
   (ii) Intensity of the image formed by half lens.

14. (a) Define 1 dioptre of power. Find the focal length of a lens of power – 2.0 D.
    (b) Why does a lemon kept in water in a glass tumbler appear to be bigger than its actual size?
    (c) Study the table given below and state the medium in which light ray will travel fastest. Why?

<table>
<thead>
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<th>C</th>
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<tbody>
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<td>1.33</td>
<td>1.5</td>
<td>2.4</td>
</tr>
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</table>

15. (a) State the laws of refraction
    (b) What is meant by the term absolute refractive index? The speed of light in a transparent medium is 0.6 times that in vacuum. Find refractive index of the medium.
    (c) How should a ray of light be incident on a rectangular glass slab so that it comes out from the opposite side of the slab without being displaced? Draw a ray diagram to illustrate your answer.

16. (a) Define optical centre of a spherical lens.
    (b) You are given a convex lens of focal length 30 cm. Where would you place an object to get a real, inverted and highly enlarged image of the object? Draw a ray diagram showing the image formation.
    (c) A concave lens has a focal length of 20 cm. At what distance from an object should an object be placed so that it forms an image at 15 cm away from the lens?

17. (i) Where should an object be placed in case of a convex lens to form an image of same size as that of the object. Show with the help of a ray diagram the position and nature of the image formed.
    (ii) With the help of ray diagram illustrate the change in position, nature and size of the image formed if the convex lens in case (i) is replaced by concave lens of same focal length.
    (iii) State the condition under which a light ray passes undeviated through a lens.

18. Which lens can be used as a magnifying glass? For which position of object does a convex lens form
    (a) a virtual and erect image?
    (b) a real and inverted image of same size as that of object?
    Same size as that of object?
Draw labeled ray diagrams to show the formation of the required image in each of the above two cases.  

19. A convex lens has a focal length of 258 cm. Calculate the distance of the object from the lens if the image is to be formed on the opposite side of the lens at a distance of 75 cm from the lens. What will be the nature of the image?  

20. A convex lens has a focal length of 20 cm. Calculate at what distance from the lens should an object be placed so that it forms an image at a distance of 40 cm on the other side of the lens. State the nature of the image formed?  

21. A convex lens has a focal length of 30 cm. Calculate at what distance from the lens should an object be placed so that it forms an image at a distance of 60 cm on the other side of the lens. Find the magnification produced by the lens in this case?  

22. A 5 cm tall object is placed perpendicular to the axis of a convex lens of focal length 20 cm. The distance of the object from the lens is 30 cm. Find the  
   (i) Position,  
   (ii) Nature  
   (iii) Size of the image formed.  

23. A 10 cm tall object is placed perpendicular to the principal axis of a convex lens of focal length 30 cm. The distance of the object from the lens is 20 cm. Find the  
   (i) Position  
   (ii) Nature  
   (iii) Size of the image formed.  

24. A 8 cm tall object is placed perpendicular to the principal axis of a convex lens of focal length 25 cm. The distance of the object from the lens is 30 cm. Find the  
   (i) Positions  
   (ii) Nature  
   (iii) Size of the image formed.  

25. Find the focal length of a lens whose power is given as+2.0 D.  

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PUZZLE . . .

✦ Across  
2. I take everyone diminished to the virtual world. (12)  
3. Due to the shape of my surface, I converge the light. (7)  
4. The effect of refraction in my surfaces always lead to a virtual image. (11)  

✦ Down  
1. I act the same for all object. (12)  
5. My shape gives a magnification of unity. (5)  

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SOLUTION & KEY

WARM UP  
1. Refraction of light shall not occur when light is incident normally on a boundary of two media and boundary that separates the two media which have equal refractive indices.

2. The wavelength of visible light varies from $4 \times 10^{-7} \text{ m}$ to $8 \times 10^{-7} \text{ m}$. The red color has the largest wavelength ($\approx 8 \times 10^{-7} \text{ m}$) and violet color has the shortest wavelength ($\approx 4 \times 10^{-7} \text{ m}$).

3. It happens on account of refraction of light. A ray of light starting from the coin goes from water to air and bends away from normal. Therefore, bottom of the beaker on which the coin lies appears to be raised.

4. Lateral magnification produced by a lens is the ratio of size of image ($h_2$) to the size of the object ($h_1$). It is represented by $m$; $m = \frac{h_2}{h_1} = \frac{v}{u}$

5. As refractive index = $\frac{\text{real depth}(x)}{\text{apparent depth}(y)}$ \therefore $y = \frac{3x}{4} = 3 \times \frac{4}{4} = 3 \text{ m}$

6. When the image formed is virtual and erect, magnification is positive. And when the image formed is real and inverted, magnification is negative.

7. Power=+1 D or Focal length = $\frac{1}{+1D} = \frac{1}{+1\text{m}^{-1}} = 1\text{m} \Rightarrow f = 1\text{m}$

   It means a lens of focal length of one meter has a power of +1D

8. As per sign convention, both concave lens and concave mirror have negative focal length. So, lens is a concave lens and mirror is a concave mirror.

9. Distance of the image from the lens, $v = 50 \text{ cm}$
   Distance of the object from the lens, $u = ?$

   Size of the image, $I = \text{Size of the object, O}$

   From the definition, if ‘$h$’ is the height of the image and that of the object,

   Magnification = $\frac{I}{O} = \frac{-h}{h} = -1$ \[\therefore \text{The image is in verted}\]

   For a lens, magnification = $\frac{v}{u}$; \therefore $\frac{v}{u} = -1 \Rightarrow u = -v = -50 \text{ cm}$

   So, the needle (the object) is placed at a distance of 50 cm in front of the lens.

   Using the lens formula, $\frac{1}{f} = \frac{1}{v} - \frac{1}{u}$ \therefore $\frac{1}{f} = \frac{1}{50 \text{ cm}} - \frac{1}{-50 \text{ cm}} = \frac{2}{50 \text{ cm}} = \frac{1}{25 \text{ cm}} \therefore f = 25 \text{ cm}$

   Then, power of the lens = $\frac{100}{f \text{(cm)}} = \frac{100}{25} \text{ D} = 4 \text{ D}$

10. Yes, it will produce a complete image of the object, as shown in figure. This can be verified experimentally by observing the image of a distance object like tree on a screen, when lower half of the lens is covered with a black paper. However, the intensity or brightness of image will reduce.
11. Here, object size, \( h_1 = 5 \text{ cm} \)
Object distance, \( u = -25 \text{ cm} \); Focal length of lens, \( f = 10 \text{ cm} \)
Image distance, \( v = ? \), image size, \( h_2 = ? \)
As \( \frac{1}{v} - \frac{1}{u} = \frac{1}{f} \)
\( \frac{1}{v} = \frac{1}{f} + \frac{1}{10} \)
\( \frac{1}{v} = \frac{5}{25} \)
\( v = \frac{50}{3} = 16.67 \text{ cm} \)
As \( v \) is positive, the image formed is real; on the right side of the lens, as shown figure above
As \( m = \frac{h_2}{h_1} = \frac{v}{u} \)
\( \frac{h_2}{5} = \frac{50}{-25} \)
\( h_2 = -10 \times \frac{3}{3} = -3.3 \text{ cm} \)
Negative sign shows that the image is inverted

12. Here, focal length of lens \( f = -15 \text{ cm} \)
Image distance, \( v = -10 \text{ cm} \); Object distance, \( u = ? \)
As \( \frac{1}{f} - \frac{1}{v} = \frac{1}{u} \)
\( \frac{1}{f} = \frac{1}{u} - \frac{1}{v} \)
\( f = \frac{1}{-10} + \frac{1}{15} = \frac{-3 + 2}{30} = \frac{-1}{30} \)
\( u = -30 \text{ cm} . \) Now, ray diagram of image is drawn adjacent.

13. Here, focal length, \( f = ? \), power, \( P = -2.0 \text{ D} \)
As \( u = -30 \text{ cm} \) \( f = \frac{100}{P} \Rightarrow f = \frac{100}{-2.0} = -50 \text{ cm} \)
As power of lens is negative, the lens must be concave.

14. Power of the lens, \( P = +1.5 \text{ D} = +1.5 \text{ m}^{-1} \)
Focal length of the lens, \( f = \frac{1}{\text{m}^{-1}} = 0.667 \text{ m} = m = 66.7 \text{ cm} \)
Thus, the focal length of the lens is 66.7 cm
Since the focal length of the lens is positive, hence the given lens is a converging lens.

15. i) A lens is a piece of transparent glass bound by two spherical surfaces.
ii) The working of lens is based on the refraction of light rays when they pass through it.
iii) There are two types of lenses.
They are: Concave lens, Convex lens.
iv) Convex lens is thick at the centre and thin at the edges
v) Concave lens is thin at the centre and thin at the edges
vi) Convex lens is known as a converging lens because it converges (bring to a point), a parallel beam of light rays passing through it.

16. a) A concave lens is also known as diverging lens because it diverges (spreads out) parallel to the axis, appear to be diverge after passing through the concave lens.

17. According to the new Cartesian sign convention:
Refraction of Light

i) All distances are measured from optical centre of the lens.
ii) The distances measured in the same direction as that of incident light are taken as positive.
iii) The distance measured against the direction of incident light are taken as negative.
iv) The distances measured upward and perpendicular to the principal axis are taken as positive.
v) The distances measured downward and perpendicular to the principal axis are taken as negative.

18. Here, the real image is formed on the wall which is at a distance of 12 cm from the convex lens. This means that the distance of image from the convex lens or image distance will be 12 cm. Since a real image is formed on the right side of the lens, so this distance will be positive.

Now, Image distance, \( v = + 12 \text{ cm} \) (A real image)
Object distance, \( u = ? \) (To be calculated)
Focal length, \( f = + 10 \text{ cm} \) (It is a convex lens)

Putting these values in the lens formula:

\[
\frac{1}{u} - \frac{1}{f} = \frac{1}{v}
\]

we get:

\[
\frac{1}{12} - \frac{1}{10} = \frac{1}{u}
\]

\[
\frac{12 - 10}{120} = \frac{1}{u}
\]

\[
\frac{2}{120} = \frac{1}{u}
\]

\[
\frac{1}{u} = \frac{60}{2}
\]

\[
u = \frac{2}{60}
\]

So, Object distance, \( u = -60 \text{ cm} \)

Thus, the object should be placed at a distance of 60 cm in front of the convex lens. The minus sign shows that the object is on the left side of the lens.

19. (i) \( \frac{1}{f} = \frac{1}{0.5} = +2 \text{ D} \)

(ii) Here, \( R_1 = 9 \text{ cm} \), \( R_2 = -15 \text{ cm} \), \( f = +12 \text{ cm} \) \( n = ? \) From lens maker’s formula,

\[
\frac{1}{f} = (n-1) \left( \frac{1}{R_1} - \frac{1}{R_2} \right)
\]

\[
\frac{1}{12} = (n-1) \left( \frac{1}{9} - \frac{1}{15} \right) = (n-1) \times \frac{8}{45}
\]

\[
n - 1 = \frac{45}{12 \times 8} = \frac{15}{32} \cdot n - 1 + \frac{15}{32} = \frac{47}{32} = 1.5
\]

(iii) Here, \( f_a = +20 \text{ cm} \), \( f_w = ? \), \( n_w = 1.33 \), \( n_g = 1.5 \)

As \( \frac{1}{f_a} = \left( \frac{n_g}{n_a} - 1 \right) \left( \frac{1}{R_1} - \frac{1}{R_2} \right) \); \( \frac{1}{20} = \left( \frac{1.5}{1} - 1 \right) \left( \frac{1}{R_1} - \frac{1}{R_2} \right) \) \( \Rightarrow \frac{1}{R_1} - \frac{1}{R_2} = \frac{1}{10} \)

Again, \( \frac{1}{f_w} = \left( \frac{n_g}{n_w} - 1 \right) \left( \frac{1}{R_1} - \frac{1}{R_2} \right) \); \( \frac{1}{f_w} = \left( \frac{1.5}{1.33} - 1 \right) \left( \frac{1}{10} \right) \times \frac{1}{10} = \frac{0.17}{1.33} \times \frac{1}{10} \); \( \frac{1}{f_w} = \frac{1.33 \times 10}{1.017} = 78.23 \text{ cm} \)

20. Object is on the left of optical centre O.

\( \therefore \) \( u = -30 \text{ cm} \)

and focal length of concave lens is taken negative

\( \therefore \) \( f = -12 \text{ cm} \)

Using lens formula,

\[
\frac{1}{v} - \frac{1}{u} = \frac{1}{f} \Rightarrow \frac{1}{v} - \left( \frac{1}{-30} \right) = \frac{1}{-12}
\]

\[
\Rightarrow \frac{1}{v} = \frac{1}{12} - \frac{1}{30} = \frac{5-2}{60} = -\frac{7}{60} \Rightarrow v = -\frac{60}{7} \text{ cm} \Rightarrow v = -8.57 \text{ cm}
\]

v is negative, it means that image is on the left of the optical centre O.
21. Here \[ |m| = \frac{1}{2} \Rightarrow m = +\frac{1}{2} \text{ or } m = -\frac{1}{2} \]

In case of concave lens the image is always virtual. Therefore, \( m \) is positive.

\[ \therefore \text{Here we consider only positive magnification, i.e., } m = +\frac{1}{2} \Rightarrow \frac{v}{u} = \frac{1}{2} \Rightarrow v = \frac{u}{2} \]

Using lens formula:

\[ \frac{1}{v} - \frac{1}{u} = \frac{1}{f} \]

For concave lens \( f = -20 \text{ cm} \Rightarrow \frac{2}{u} - \frac{1}{u} = \frac{1}{-20} \Rightarrow \frac{1}{u} = -\frac{1}{20} \Rightarrow u = -20 \text{ cm} \)

\[ \therefore -20 \text{ cm means the object is to the left of the optical centre } O. \]

22. (a) Object is on the left of \( O \). \( \therefore u = -16 \text{ cm} \)

And \( f = +12 \text{ cm} \) (\( \because \) convex lens)

Using lens formula:

\[ \frac{1}{v} - \frac{1}{u} = \frac{1}{f} \Rightarrow \frac{1}{v} = \frac{1}{12} - \frac{1}{16} = \frac{4-3}{48} = \frac{1}{48} \Rightarrow v = +48 \text{ cm} \]

\( v \) is positive means that image is on the right of \( O \).

(b) Magnification for lens is:

\[ m = \frac{h'}{h} = \frac{v}{u} \]

Here \( v = +40 \text{ cm} \), \( u = -16 \text{ cm} \), \( h = 2 \text{ cm} \) \( \Rightarrow \frac{h'}{2} = \frac{48}{-16} \Rightarrow h' = -6 \text{ cm} \)

\[ \therefore \text{image is inverted and } 6 \text{ cm is size.} \]

(c) To find nature of the image, find magnification \( m \).

If \( m \) is negative then image is real

If \( m \) is positive then image is virtual. Here \( m = \frac{v}{u} = \frac{48}{-16} \Rightarrow m = -3 \)

\[ \therefore \text{image is real and inverted.} \]

23. (a) Object is on the left of \( O \). \( \therefore u = -30 \text{ cm} \)

And \( f = -15 \text{ cm} \) (\( \because \) concave lens); Using lens formula:

\[ \frac{1}{v} - \frac{1}{u} = \frac{1}{f} \]

\[ \Rightarrow \frac{1}{v} = \frac{1}{-30} \Rightarrow \frac{1}{v} = \frac{1}{-30} = \frac{-2}{30} = -\frac{3}{30} = -\frac{1}{10} \Rightarrow v = -10 \text{ cm} \]

\( v \) is positive means that image is on the right of \( O \).

(b) Magnification for lens is;

\[ m = \frac{h'}{h} = \frac{v}{u} \]

Here \( v = -30 \text{ cm} \), \( v = -10 \text{cm} \), \( h = 3 \text{ cm} \) \( \Rightarrow \frac{h'}{3} = \frac{-10}{-30} = \frac{1}{3} \Rightarrow h' = 1 \text{ cm} \)

\[ \therefore h' \text{ is positive means image is erect.} \]

(c) \( m = \frac{v}{u} = \frac{-10}{-30} = \frac{1}{3} \Rightarrow m = \frac{1}{3} \)

\[ \therefore m \text{ is positive means image is virtual and erect.} \]

24. No. The lens of the eye converges the divergent beam of light (that produces virtual image) to the retina, thereby forming a real image of the virtual object.
25. The focal length of a mirror does not depend upon the nature of the medium in which it is placed whereas the focal length of a lens depends upon the medium in which it is placed. Thus there will be no change in the focal length of the concave mirror where as the focal length of the convex lens will change.

26. Every part of a lens forms a complete image. If the lower part of the lens is blackened the complete image will be formed but its intensity will decrease.

27. Yes. The type of lens changes if it is placed in a medium having a higher refractive index than that of the lens.

28. E

29. The angle of reflection is equal to the angle of incidence but the angle of refraction is not equal to the angle of incidence.

30. (i) Crown glass to Water  
(ii) Water to Diamond

31. (a) 100 cm, 60 cm, 40 cm, 30 cm, 24 cm, 25.7 cm  
(b) 25.7 cm  
(c) 25 cm  
(d) 20 cm  
32. 7.14 cm

33. True  
34. False  
35. True  
36. True  
37. True  
38. False  
39. False  
40. True  
41. False  
42. True  
43. Two rays  
44. Optical axis  
45. One

46. Wavelength  
47. Positive, negative  
48. lens  
49. Normal  
50. Parallel

51. Refraction  
52. Diamond  
53. 4  
54. 3  
55. 2  
56. 2

57. 2  
58. 2  
59. 2  
60. 1  
61. 4  
62. 4  
63. 3

64. 4  
65. 2  
66. 2  
67. 3  
68. 3  
69. 1  
70. 2

71. 4  
72. 3  
73. 73.  
74. 1

**HOMEWORK SHEET**

1. The refractive index of a medium is the ratio of velocity of light in vacuum to the velocity of light in medium.

2. Here \( n_g = \frac{3}{2} \), \( n_s = \frac{1}{3} \); \( n_g = \frac{1}{3/2} = \frac{2}{3} \)

3. The optical centre of a lens is a point on the principal axis of the lens, such that a ray of light passing through it goes undeviated.

4. A real image can be taken on a screen, because the refracted rays actually meet at a point on the screen. A virtual image cannot be taken on a screen, because the refracted rays only appear to come from a point and do not meet there actually.

5. The generalized observation is Lateral displacement of a ray of light \( \propto \frac{1}{\text{Wavelength of light}} \). This is because the wavelength of violet light is shorter than that for the red light.

6. Yes, the velocity of light changes when it goes from one medium to another.

7. The object should be placed at a distance equal to twice the focal length of the lens.

8. A convex lens forms a virtual and erect image, when the object is situated between optical centre and principal focus of the lens.

9. When a ray of light travels from air into water obliquely, it bends towards the normal. This is because water is optically denser than air. On entering water, speed of light decreases and the light bends towards normal.

10. Here, refractive index, \( n = 1.5 \) of light in vacuum = \( 3 \times 10^8 \) ms\(^{-1} \)
Refraction of Light

Speed of light in glass, \( v = ? \) From \( n = \frac{c}{v} \Rightarrow v = \frac{c}{n} = \frac{3 \times 10^8}{1.5} = 2 \times 10^8 \text{ ms}^{-1} \)

11. The medium with highest optical density is diamond and it’s refractive index is maximum (=2.42), also, the medium with lowest optical density is air and its refractive index is minimum (=1.0003).

12. We know from the definition of refractive index, that the speed of light is higher in a medium with lower refractive index. So, the light travels fastest in water relative to kerosene and turpentine.

13. This statement means that the speed of light in diamond is lower by a factor of 2.42 relative to that in vacuum.

14. The power of a lens whose focal length is one meter (1m) is one dioptre.

15. Focal length of the concave lens = -2 m

So, power of the concave lens = \( \frac{1}{-2} = -0.5D \)

16. (a) The incident ray, the refracted ray and the normal at the point of incidence, all lie in the same plane.

(b) The ratio of the sine of the angle of incidence to the sine of the angle of refraction is constant for the pair of given media.

17. Speed of light in glass increases on increasing the wavelength of light.

18. a) Suppose a parallel beam of light rays falls on a convex as shown in the diagram. These rays are parallel to each other and also parallel to the axis of the lens. These rays pass through the convex lens and get refracted (or bent) according to the law of refraction and converge at a point. Since these parallel light rays converge at a point this lens is also called as convex lens.

b) The focal length a lens is defined as the point on its principal axis converge after passing through the lens focal length is a distance between principal focus and optical centre of a lens.

19. For refraction at A,

\[ i = 37^\circ; \ r = ? \ n = 1.2 \]

Using Snell’s laws, \( n = \frac{\sin i}{\sin r} \Rightarrow 1.2 = \]

\[ \frac{\sin 37}{\sin r} \Rightarrow 1.2 = \frac{3}{5} \times \frac{1}{\sin r} \Rightarrow \sin r = \frac{1}{2} \]

\[ \Rightarrow r = 30^\circ \]

20. (a) \( n_g = \frac{c_{\text{air}}}{c_{\text{glass}}} \ n_g = \frac{c_{\text{air}}}{c_{\text{glass}}} \quad \therefore \ c_{\text{glass}} = \frac{c_{\text{air}}}{n_g} = \frac{3 \times 10^8}{1.5} = 2 \times 10^8 \text{ ms}^{-1} \)
(b) Frequency of wave does not change with change in optical medium, hence remains the same.

\[
\frac{\text{Speed of light in air}}{\text{Speed of light in glass}} = \frac{\text{Wavelength of light in air}}{\text{Wavelength of light in glass}}
\]

\[
\Rightarrow \frac{3 \times 10^8 \text{ms}^{-1}}{2 \times 10^8 \text{ms}^{-1}} = \frac{500 \times 10^{-9}}{\text{Wavelength of light in glass}}
\]

\[
\therefore \text{Wavelength of light in glass} = \frac{500 \times 2 \times 10^{-9}}{3} = 333.3 \text{nm}
\]

21. (i) To calculate the position:

\[
m = \frac{h_i}{h_o} = \frac{h_o}{5} = \frac{1}{5}
\]

Also, \( m = -\frac{v}{u} \); \( \Rightarrow \frac{1}{5} = -\frac{v}{u} \)

\([\because u \text{ is always } -ve] \Rightarrow v = 6 \text{ cm}\)

Thus, image is formed at a distance of 6 cm behind the mirror.

(ii) To calculate the focal length:

\[
\frac{1}{f} = \frac{1}{u} + \frac{1}{v} \quad \left[ u \text{ is always negative} \right]
\]

\[
\Rightarrow \frac{1}{f} = \frac{1}{-30} + \frac{1}{6} \Rightarrow \frac{1}{f} = -\frac{1}{30} + \frac{5}{30} \Rightarrow \frac{1}{f} = \frac{4}{30} \Rightarrow f = \frac{30}{4} = 7.5 \text{ cm}
\]

Thus, the focal length of the diverging mirror is 7.5 cm

22. (i) To calculate the position:

Distance of object from the pole, \( u = -27 \text{ cm} \)

\([\because u \text{ is always negative}]\)

Distance of image from the pole, \( v = ? \)

Focal length of concave mirror, \( f = -18 \text{ cm} \)

\([\because f \text{ for concave mirror is negative}]\)

Now, \( \frac{1}{f} = \frac{1}{u} + \frac{1}{v} \); \( \Rightarrow \frac{1}{-18} = \frac{1}{-27} + \frac{1}{v} \); \( \Rightarrow \frac{1}{v} = \frac{1}{54} \Rightarrow v = -54 \Rightarrow v = -54 \text{ cm} \)

Thus, the image is formed at a distance of 54 cm in front of the concave mirror.

(ii) To calculate size:

\[
\Rightarrow \frac{h_i}{h_o} = -\frac{h_o}{7.0} = -\frac{54}{-27} \Rightarrow h_i = -2 \times 7.0 = -14 \text{ cm}
\]

Thus, size of image is 14 cm and it is an inverted, magnified and real image.

23. Here, \( n_2 = -1.5, n_1 = 1 \), for air

\[
R_1 = +20 \text{ cm}, R_2 = -20 \text{ cm}
\]

\[
\Rightarrow \frac{1}{f_1} = \left( \frac{n_2}{n_1} - 1 \right) \left( \frac{1}{R_1} - \frac{1}{R_2} \right) = \left( \frac{1.5}{1} - 1 \right) \left( \frac{1}{20} + \frac{1}{20} \right) = \frac{1}{20} \Rightarrow P_1 = \frac{100}{f_1} = 100 \text{ cm} = 5 \text{D}
\]

When lens is immersed inside a liquid of refractive index 1.5, \( n_1 = 1.25 \)

\[
\Rightarrow \frac{1}{f_2} = \left( \frac{n_2}{n_1} - 1 \right) \left( \frac{1}{R_1} - \frac{1}{R_2} \right) = \left( \frac{1.5}{1.25} - 1 \right) \left( \frac{1}{20} + \frac{1}{20} \right) = \frac{1}{50} \Rightarrow P_2 = \frac{100}{f_2} = 100 \text{ cm} = 2 \text{D} \Rightarrow \frac{P_2}{P_1} = \frac{5}{2} = 2.5
\]

24. Hold the given piece of glass over some printed matter.

(i) If the letters appear magnified, the given piece is a convex lens.

(ii) If the letters appear diminished, the given piece is a concave lens.

(iii) If the letters appear to be of the same size, then it is a plane glass piece.

25. (i) When \( n_1 > n_2 \) light goes from rarer to denser medium, Therefore, in passing through a concave lens, it diverges.

(ii) When \( n_1 = n_2 \), there is no change in medium. Therefore, no bending or refraction occurs.
(iii) When \( n_1 < n_2 \), light goes from a denser to a rarer medium. Therefore, in passing through a concave lens, it converges.

26. (a) 0°
27. (a) Obliquely; making a large a denser medium to a rarer medium
(b) At right angles (90°) to the surface of substance.
28. (i) A (ii) D
29. (a) 7.14 cm; (b) 10 cm
30. + 2.81 cm
31. (a) 10 cm (b) 5 cm (c) Convex lens (d) Convex lens
32. (a) \( v = + 6.66 \) cm. The film should be at a distance of 6.66 cm behind the camera lens
(b) 1.66 cm (c) Convex lens
33. \( f = - 66.7 \) cm. Concave lens
34. (a) Convex lens (b) + 15 cm
35. (a) Thinner at the middle (b) Lens of lower power: \(- 3.50 \) D. (c) Left eye
36. (a) Thicker in the middle (b) Lens having greater power of + 2.50 D
(c) Converge light rays.
42. False 43. True 44. False 45. False 46. False
47. False 48. Greater 49. 4 m 50. Aperture
51. Plano convex lens 52. Less denser 53. One 54. Dioptrometer
55. Optically denser 56. 45° 57. Power 58. 3.33 dioptre 59. 3 60. 1
61. 3 62. 4 63. 2 64. 2 65. 2 66. 2 67. 4
68. 4 69. 4 70. 3 71. 4 72. 1 73. 3 74. 3
75. 3 76. 4 77. 2 78. 3

EXAM FOCUS
1. It will act as a concave lens.
2. In medium A.
3. It means that light travels 2.42 times faster in vacuum than in diamond.
4. It bends because its velocity changes when it moves from one medium into the other.
5. The diagram is as shown:

6. The two diagrams are as shown below:
7. We will keep the lens close to some page of a book and see the print of the book through it. If the letters of the book appears enlarged, it is a convex lens and if they appear diminished, it is concave lens.

8. (a) No refraction or bending would take place. The light will travel in straight line.
(b) The refraction occurs due to change in speed of light as it enters from one medium to another.

9. (a) The diagram is as shown:
(b) It means ratio of speed of light in vacuum to the speed of light in diamond is equal to 2.42.

10. Given, \( f = 20 \text{ cm}, \ u = -30 \text{ cm}, \ v = ? \)

Using the lens formula \( \frac{1}{v} - \frac{1}{u} = \frac{1}{f} \) we have \( \frac{1}{v} = \frac{1}{u} + \frac{1}{f} = \frac{1}{-30} + \frac{1}{20} = \frac{1}{60} \). Therefore, \( v = 60 \text{ cm} \).

The labeled diagram is as shown below:

11. When a ray of light travels through a glass slab from air, it bends towards the normal and when it comes out of the other side of the glass slab it bends away from the normal. It is found that the incident ray and the emergent ray are not along the same straight line, but the emergent ray seems to be displaced with respect to the incident ray. This shift in the emergent ray with respect to the incident ray is called lateral shift or lateral displacement. The incident and the emergent rays, however, remain parallel.

12. (i) When object optical centre and principal focus of a convex lens.
(ii) When object lies between F and 2F of a concave lens

(iii) When object lies at 2F

(i) \( m = +ve, \ m > 1 \) and (ii) \( m + ve \ m < 1 \)

13. (a) (i) Between F and 2F of a lens.
   (ii) Within the focal length.

(b)

(c) No effect on focal length, but intensity decreases.

14. (a) (i) One dioptre is the power of a lens focal length one metre.
   (ii) Using \( P = 1/f - 2.0 = 1/f \) (m) or \( f = -0.5 \) m

(b) This is due to the phenomenon of refraction of light. A ray of light starting from the lemons kept in water reaches the water – air interface and bends away from normal. To the observer, it appears as the light ray is coming from the point above the actual point. This apparent position makes them appear bigger in size.

(c) The light ray will travel fastest in medium with least refractive index i.e., medium A.

15. (a) The laws of refraction are:
   (i) The incident ray, the refracted ray and the normal to the interface of two transparent media at the point of incidence, all lie in the same plane.
   (ii) The ratio of the sine of the angle of incidence to the sine of angle refraction is a constant, for the light of a given colour and for the given pair of media.

(b) (i) The absolute refractive index of a medium is defined as the ratio of speed of light in
Refraction of Light

(i) The speed of light in vacuum = c. The speed of light in a medium = 0.6 c

Thus, refractive index is \( \frac{\text{speed of light in vacuum}}{\text{speed of light in air}} = \frac{c}{0.6c} = 1.66 \)

(c) The ray of light should be incident normally to the surface of the glass slab.

16. (a) It is the central point of the lens through which a ray of light passes without suffering any deviation.
   (b) The object will be placed at F.

(c) \( f = -20 \text{ cm}, \ u = ?, \ v = -15 \text{ cm}, h = \) Using the expression \( \frac{1}{f} = \frac{1}{v} - \frac{1}{u} \), we have \( \frac{1}{-20} = \frac{1}{-15} - \frac{1}{u} \) or \( u = 60 \text{ cm} \)

17. (i) Object should be placed at 2F. The diagram is as shown:
   (ii) The diagram is as shown:
   (iii) When it passes through the optical centre of the lens.

18. Convex lens can be used as magnifying glass
   (a) When object is between optical centre C and focus \( F_1 \)
   (b) When object is at 2\( F_1 \)

19. Given \( f = +25 \text{ cm}, \ v = 75 \text{ cm}, u = ? \) Using \( \frac{1}{v} - \frac{1}{u} = \frac{1}{f} \) we have; \( \frac{1}{u} = \frac{1}{v} - \frac{1}{f} = \frac{1}{75} - \frac{1}{+25} = -\frac{2}{75} \)
    Therefore \( u = 37.5 \text{ cm} \); The image is real, inverted and magnified.

20. Given \( f = +20 \text{ cm}, \ v = 40 \text{ cm}, u = ? \) Using \( \frac{1}{v} - \frac{1}{u} = \frac{1}{f} \) we have; \( \frac{1}{u} = \frac{1}{v} - \frac{1}{f} = \frac{1}{40} - \frac{1}{+20} = -\frac{1}{40} \)
Therefore \( u = -40 \text{ cm} \). The image is real and inverted.

21. Given \( f = +30 \text{ cm}, v = 60 \text{ cm}, u = ? \) Using \( \frac{1}{v} - \frac{1}{u} = \frac{1}{f} \)
we have \( \frac{1}{u} - \frac{1}{v} = \frac{1}{u} - \frac{1}{f} = \frac{1}{-30} - \frac{1}{60} \)
Therefore \( u = -60 \text{ cm} \). The magnification produced is given by
\[
m = \frac{v}{u} = \frac{60}{-60} = -1; \]
The negative sign shows that the image is real and inverted.

22. Given \( O = 5 \text{ cm}, u = -30 \text{ cm}, f = +20 \text{ cm}, v = ? \) And \( I = ? \)
Using \( \frac{1}{v} - \frac{1}{u} = \frac{1}{f} \)
we have \( \frac{1}{v} - \frac{1}{u} = \frac{1}{f} = \frac{1}{20} - \frac{1}{-30} = \frac{1}{60} \)
Therefore \( v = 60 \text{ cm} \);
Also \( m = \frac{I}{O} = \frac{v}{u} \), therefore \( m = \frac{60}{30} = 2 \) solving we have; \( I = -10 \text{ cm} \)

23. Given \( O = 10 \text{ cm}, u = -20 \text{ cm}, f = +30 \text{ cm}, v = ? \) And \( I = ? \)
Using lens formula \( \frac{1}{v} - \frac{1}{u} = \frac{1}{f} \)
we have \( \frac{1}{v} - \frac{1}{u} = \frac{1}{f} = \frac{1}{30} + \frac{1}{-20} = \frac{1}{60} \)
Therefore \( v = -60 \text{ cm} \);
Also \( m = \frac{I}{O} = \frac{v}{u} \), therefore \( m = \frac{-60}{-20} = 3 \) solving we have
\( I = +30 \text{ cm} \); The image is virtual, erect and magnified.

24. Given \( O = 8 \text{ cm}, u = -30 \text{ cm}, f = +25 \text{ cm}, v = ? \) And \( I = ? \)
Using lens formula \( \frac{1}{v} - \frac{1}{u} = \frac{1}{f} \)
we have \( \frac{1}{v} - \frac{1}{u} = \frac{1}{f} = \frac{1}{25} + \frac{1}{-30} = \frac{1}{150} \)
Therefore \( v = 150 \text{ cm} \);
Also \( m = \frac{I}{O} = \frac{v}{u} \), therefore \( m = \frac{150}{-30} = -5 \) solving we have \( I = -40 \text{ cm} \)
The image is real and inverted.

25. Given \( P = +2 \text{ D} \);
We know that \( P = \frac{1}{f(m)} \);
Therefore \( f = \frac{1}{P} = \frac{1}{2} = +0.5 \text{ m} \)
The positive sign indicates that it is a convex lens.
Refraction of Light

**Refraction of light:** The bending of light when it passes obliquely from one transparent medium to another is called refraction of light.

**Medium:** A transparent substance in which light travels is known as a medium. A medium in which the speed of light is more is known as an optically rarer medium. A medium in which the speed of light is less is known as an optically denser medium.

**Laws of refraction:**
(i) The incident ray, the refracted ray and the normal to the surface separating two medium all lie in the same plane.
(ii) The ratio of the sine of the incident angle ($\theta_i$) to the sine of the refracted angle ($\theta_r$) is constant. i.e., $n = \frac{\sin \theta_i}{\sin \theta_r}$ = constant. This constant is known as the refractive index of second medium with respect to the first medium.

**Lateral shift (displacement):** The perpendicular distance between the original path of the incident ray and the emergent ray coming out of a glass slab is called lateral shift.

**Lens:** If is a transparent medium bounded by two spherical refracting surfaces or by one spherical and other plane refracting surfaces.

**Power of a lens:** It is defined as the reciprocal of the focal length of a lens.

**Dioptre:** It is the S.I. unit of power. One dioptre is the power of a lens where focal length is one metre.

**Lens formula:** \[ \frac{1}{f} = \frac{1}{u} + \frac{1}{v}; \]

**Magnification:** \[ m = \frac{h'}{h} = \frac{v}{u} \]

**Power of lens:** \[ P = \frac{1}{\text{Focal length (in metres)}} \]

Power of convex lens is positive. Power of a concave lens is negative.

### Solved Examples

1. An object 4 cm high is placed at a distance of 27 cm in front of a convex lens of focal length 18 cm. Find the position, nature and size of the image formed.

**Sol.**
Here, $u = -27$ cm (sign convention); $f = 18$ cm, $h_1 = 4$ cm

**Step 1.** Determination of $v$; Using, \[ -\frac{1}{u} + \frac{1}{v} = \frac{1}{f}, \]
\[ -\frac{1}{-27} + \frac{1}{v} = \frac{1}{18} \]
\[ \frac{1}{v} = \frac{1}{18} - \frac{1}{27} = \frac{1}{54} \]
\[ \therefore v = 54 \text{ cm. (Positive of image)} \]

**Step 2.** Determination of $h_2$; Using, \[ \frac{h_2}{h_1} = \frac{v}{u}, \]
we get; \[ h_2 = \frac{v}{u} \times h_1 = \frac{54}{-27} \times 4 = -8 \text{ cm} \]

Thus, size of image is 8 cm, negative sign shows that the image is inverted.
2. An object of 5 cm is placed 20 cm away from a converging lens of focal length 10 cm. Draw the ray diagram to produce the image and find the position, size and the nature of the image formed.

Sol. In this case, \( f = + 10 \text{ cm} \), \( u = -20 \text{ cm} \), \( h_1 = 5 \text{ cm} \). Here, object is placed 20 cm away from the lens of focal length 10 cm, so object is at 2F. So the image of the object will be formed at 2F on right side of the lens. The image formed will be real inverted and of the same size as that of object as shown in the diagram. \( h_1 = 5 \text{ cm} \), \( u = -20 \text{ cm} \), \( f = 10 \text{ cm} \)

**Step 1.** Using \( \frac{1}{u} + \frac{1}{v} = \frac{1}{f} \) we have \( \frac{1}{(-20)} + \frac{1}{v} = \frac{1}{10} \) or \( \frac{1}{v} = \frac{1}{10} - \frac{1}{20} = \frac{1}{20} \) : \( v = +20 \text{ cm} \)

Positive sign shows that a real image is formed.

**Step 2.** Using, \( \frac{h_2}{h_1} = \frac{v}{u} \), we have \( h_2 = \frac{v}{u} h_1 = \frac{20}{-20} \times 5 = -5 \text{ cm} \)

Negative sign shows that the image formed is inverted. Thus, image formed is real, inverted and of the same size as that of the object.

3. A convex lens forms a real and inverted image of a needle at a distance of 25 cm from the lens. If the image is of the same size as that of the needle, then where should the needle be placed in front of the lens. Also calculate the power of the lens.

**Sol.** **Step 1.** We know, if the size of the real and inverted image is same as that of the object, then the object is at 2F and image is also formed at 2F on the other side of the convex lens.

\( \therefore u = -25 \text{ cm} \)

Also \( \frac{h_2}{h_1} = \frac{v}{u} \) or \( \frac{v}{u} = 1 \) \( (\because h_2 = h_1) \) or \( v = u = 25 \text{ cm} \)

Using \( \frac{1}{u} + \frac{1}{v} = \frac{1}{f} \), we get; \( \frac{1}{f} = \frac{1}{25} + \frac{1}{25} = \frac{2}{25} \) or \( f = \frac{25}{2} = 12.5 \text{ cm} \)

In this case, \( 2f = 25 \text{ cm} \) or \( f = 12.5 \text{ cm} \)

Thus, needle must be placed at a distance of 25 cm in front of the convex lens.

**Step 2.** Now, power of lens, \( P = \frac{100}{f} \text{ (in cm)} = \frac{100}{12.5} = +8.0 \text{ D} \)

4. Find the focal length of a lens of power \(-1.0 \text{ D}\). What type of lens is this?

**Sol.** Using \( P = \frac{100}{f} \text{ (in cm)} \); Here, \( P = -1.0 \text{ D} \) \( \therefore f = \frac{100}{P} = \frac{100}{-1} = -100 \text{ cm} \)

Since the power and focal length are negative, so the given lens is concave lens.

5. A lens used in spectacles has power \(+2.0 \text{ D}\). What is the focal length of the lens? Is the lens a converging or diverging?

**Sol.** Here, \( P = +2.0 \text{ D} \); Using, \( P = \frac{100}{f} \text{ (cm)} \) we get; \( f = \frac{100}{P} = \frac{100}{2} = 50 \text{ cm} \)

Since power and focal length of the lens are positive, so the given lens is converging.
**SINGLE CORRECT CHOICE TYPE:**

1. Due to refraction of light in atmosphere
   1) stars appear twinkle
   2) the sun appears to be oval in morning and evening
   3) The period of visibility of the sun is increased
   4) all of these

2. For prism of refractive index 1.732, the angle of minimum deviation is equal to the angle of the prism. The angle of the prism is
   1) $80^\circ$  
   2) $70^\circ$  
   3) $70^\circ$  
   4) $50^\circ$

3. When white light enters a prism, it gets split into its constituent colors. This is due to
   1) high density of prism material
   2) value of $\mu$ is different for different $\lambda$
   3) Diffraction of light
   4) velocity changes for different frequencies

4. Which of the following correctly represents graphical relation between sine of angle of incidence ($i$) and sine of angle of refraction ($r$)?
   ![Graphical Relations](image)
   1)  
   2)  
   3)  
   4)  

5. An object is placed at a distance of 4 cm from a concave lens of focal length 12 cm. The nature of image is
   1) 0.75
   2) 0.65
   3) 0.55
   4) 0.45

6. With regard to refraction which of the following statement is false
   1) It is a change in direction of light when it passes from one transparent medium into another of different optical density
   2) Light is deviated away from the normal when it enters an optically dense medium from a lens dense medium
   3) The velocity of light is changed during refraction
   4) the wavelength of the light is changed during refraction

7. The following are true about the refractive index of a material
   1) The absolute refractive index of a material is always greater than its refractive index
   2) The refractive index of a material is usually measured with ultraviolet light
   3) The refractive index of a medium differs for light of different wavelengths
   4) The deviation of light increases with the increase in refractive index of the material that it enters

8. A thick Plano convex lens made of crown glass (refractive index 1.5) has a thickness of 3 cm at its centre. The radius of curvature of its curved face is 5 cm. An ink mark made at the centre of its plane face, when viewed normally through the curved face, appears to be at a distance $x$ from the curved face. Then, $x$ is equal to
   1) 2 cm
   2) 2.1 cm
   3) 2.3 cm
   4) 2.5 cm
An object is placed in front of a screen and a convex lens is placed at a position such that the size of the image formed is 9 cm. When the lens is shifted through a distance of 20 cm, the size of the image becomes 1 cm. The focal length of the lens and the size of the object are respectively
1) 7.5 cm and 3.5 cm  2) 7.5 cm and 4 cm  3) 6 cm and 4 cm  4) 7.5 cm and 3 cm

The focal length of an equi-convex lens in air is equal either of its radii of curvature. The refractive index of the material of the lens is
1) $4/3$  2) 2.5  3) 0.8  4) 1.5

**STATEMENT TYPE QUESTIONS:**

11. **STATEMENT – 1** If plane glass slab is placed on the letters of different colours all the letters appears to be raised up to the same height.

**STATEMENT – 2** Different colours have different wavelengths.

1) Both the statements (1) and (2) are true
2) Both the statements (1) and (2) are false
3) Statement (1) is true, Statement (2) is false
4) Statement (1) is false, Statement (2) is true

12. **STATEMENT – 1** An air bubble in jar of water shines brightly due to phenomenon of refraction.

**STATEMENT – 2** Refraction of light is the phenomenon of change in the path of light, when it goes from one medium to another.

1) Both the statements (1) and (2) are true
2) Both the statements (1) and (2) are false
3) Statement (1) is true, Statement (2) is false
4) Statement (1) is false, Statement (2) is true

**COMPREHENSION TYPE:**

I. **An object of size 5 cm is kept at a distance 25 cm from the optical centre of a converging lens of focal length 10 cm.**

13. The image distance is ________________
1) 15.67 cm  2) 16.67 cm  3) 15.76 cm  4) 16.01 cm

14. The size of the image is ________
1) 2.33 cm  2) 2.32 cm  3) 3.33 cm  4) 2.22 cm

15. The nature of image is ____________
1) inverted  2) erect  3) enlarged  4) can’t say

II. **A thin convex lens of glass immersed in a liquid of refractive index n, behaves like a divergent lens of focal length 1 m. Refractive index at glass is 3/2 and power of the lens is 5 dioptrre.**

16. The focal length of lens in air is ......
1) 5 cm  2) 10 cm  3) 15 cm  4) 20 cm

17. The value of n is ...........
1) $5/3$  2) $4/3$  3) $2/3$  4) $1/3$
Matrix Match Type:
18.

<table>
<thead>
<tr>
<th>COLUMN – I</th>
<th>COLUMN – II</th>
</tr>
</thead>
<tbody>
<tr>
<td>a) Convex lens</td>
<td>p) Diverging lens</td>
</tr>
<tr>
<td>b) Concave lens</td>
<td>q) Snell’s law</td>
</tr>
<tr>
<td>c) The ratio of sine of angle of incidence to sine of angle of refraction.</td>
<td>r) Bending of light</td>
</tr>
<tr>
<td>d) Refraction of light</td>
<td>s) Converging lens</td>
</tr>
<tr>
<td>1) a → s, b → p, c → q, d → r.</td>
<td>2) a → p, b → q, c → r, d → s.</td>
</tr>
<tr>
<td>3) a → r, b → s, c → q, d → p.</td>
<td>4) a → r, b → s, c → p, d → q.</td>
</tr>
</tbody>
</table>

19.

<table>
<thead>
<tr>
<th>COLUMN – I</th>
<th>COLUMN – II</th>
</tr>
</thead>
<tbody>
<tr>
<td>a) Lens formula</td>
<td>p) ( n \sin \theta = \text{constant} )</td>
</tr>
<tr>
<td>b) ( n_{gw} )</td>
<td>q) ( \frac{v}{u} )</td>
</tr>
<tr>
<td>c) Magnification by a lens</td>
<td>r) ( \frac{1}{f} = \frac{1}{v} - \frac{1}{u} )</td>
</tr>
<tr>
<td>d) Snell’s law</td>
<td>s) ( n_{ga} \times n_{aw} )</td>
</tr>
<tr>
<td>1) a → s, b → p, c → q, d → r.</td>
<td>2) a → p, b → q, c → r, d → s.</td>
</tr>
<tr>
<td>3) a → r, b → s, c → q, d → p.</td>
<td>4) a → r, b → s, c → p, d → q.</td>
</tr>
</tbody>
</table>

Single Correct Choice Type:
1. A concave lens of glass, refractive index 1.5, has both surfaces of same radius of curvature \( R \). On immersion in a medium of refractive index 1.75, it will behave as a
1) convergent lens of focal length 3.5 \( R \)  2) convergent lens of focal length 3.0 \( R \)  3) divergent lens of focal length 3.5 \( R \)  4) divergent lens of focal 3.\( R \)
2. A convergent lens made of crown glass (refractive index 1.5) has focal length 20 cm in air. If it is immersed in a liquid of refractive index 1.60, its focal length will be
1) 160 cm  2) 100 cm  3) -80 cm  4) -160 cm
3. The plane face of a Plano-convex lens of focal length 20 cm is silvered. The lens will then behave as a concave mirror of focal length
1) 5 cm  2) 10 cm  3) 20 cm  4) 40 cm
4. A convex lens of focal length 40 cm is in contact with a concave lens of focal length 25 cm. The power of the combination in dioptre is
1) -6.5  2) -1.5  3) +1.5  4) +6.5
5. Concave and convex lenses are placed touching each other. The ratio of magnitudes of their powers is 2:3. The focal length of the system is 30 cm. Then the focal lengths of individual lenses are
1) -75 cm, 50 cm  2) -15 cm, 10 cm  3) 75 cm, 50 cm  4) 75 cm, -50 cm
6. The principal axis is also called____of the lens.
1) optical axis  2) x-axis  3) y-axis  4) None
7. A ray of light travelling in air is incident on the plane of a transparent medium. The angle of incident is 45° and that of refraction is 30°. Find the refractive index of the medium.

1) \( \frac{1}{\sqrt{2}} \) 
2) \( \frac{2}{\sqrt{2}} \) 
3) \( \frac{3}{\sqrt{2}} \) 
4) \( \sqrt{2} \)

8. The minimum distance between an object and its real image formed by a convex lens is

1) \( \frac{2}{3} f \) 
2) \( 2 f \) 
3) \( \frac{5}{2} f \) 
4) \( 4 f \)

9. A beam of white light passing through a prism is split up into its constituent colors. The light which undergoes least deviation is

1) Violet 
2) Yellow 
3) Red 
4) Green

10. Under minimum deviation condition in a prism, if a ray is incident at an angle 30°, the angle between the emergent ray and the second refracting surface of the prism is

1) 0° 
2) 30° 
3) 45° 
4) 60°

STATEMENT TYPE QUESTIONS:
11. STATEMENT – 1 The diamond shines due to multiple total internal reflections.

STATEMENT – 2 The critical angle for diamond is 24.4°.

1) Both the statements (1) and (2) are true
2) Both the statements (1) and (2) are false
3) Statement (1) is true, Statement (2) is false
4) Statement (1) is false, Statement (2) is true

12. STATEMENT – 1 Higher is the refractive index of a medium or denser the medium, lesser is the velocity of light in that medium.

STATEMENT – 2 Refractive index is inversely proportional to velocity.

1) Both the statements (1) and (2) are true
2) Both the statements (1) and (2) are false
3) Statement (1) is true; Statement (2) is false
4) Statement (1) is false; Statement (2) is true

COMPREHENSION TYPE:
I. A convex lens is made of glass of refractive index 1.5. The radius of curvature of each of its two surfaces is 20 cm. The lens is immersed inside a liquid of refractive index 1.25.

13. Power of lens in air is ____________
1) 4D 
2) 5 D 
3) 6 D 
4) 7 D

14. Power of lens inside the liquid is ____________
1) 1 D 
2) 2 D 
3) 3 D 
4) 4 D

15. Ratio of power in case of air to liquid is ____________
1) 2.5 
2) 3.5 
3) 4.5 
4) 5.5

MATRIX MATCH TYPE:
16. COLUMN – I            COLUMN – II

a) Negative magnification  p) Diminished image
b) Magnification less than 1  q) Inverted image
c) Positive magnification  r) Size of image is same
d) Magnification equal to 1  s) Erect image

1) a → q, b → p, c → s, d → r. 
2) a → p, b → q, c → r, d → s. 
3) a → r, b → s, c → q, d → p. 
4) a → r, b → s, c → p, d → q.
17. The graphs given apply to convex lens of focal length $f$, producing a real image at a distance $v$ from the optical centre when self-luminous object is at distance $u$ from the optical centre. The magnitude of magnification is $m$. Identify the following graphs with the first named quantity being plotted along $y$ – axis.

**COLUMN – I**

<table>
<thead>
<tr>
<th>Column – I</th>
<th>Column – II</th>
</tr>
</thead>
<tbody>
<tr>
<td>a) $v$ against $u$</td>
<td>p)</td>
</tr>
<tr>
<td>b) $\frac{1}{v}$ against $\frac{1}{u}$</td>
<td>q)</td>
</tr>
<tr>
<td>c) $m$ against $v$</td>
<td>r)</td>
</tr>
<tr>
<td>d) $(m + 1)$ against $\frac{v}{f}$</td>
<td>s)</td>
</tr>
</tbody>
</table>

1) a → q, b → p, c → s, d → r. 2) a → p, b → q, c → r, d → s.
3) a → r, b → s, c → q, d → p. 4) a → r, b → p, c → q, d → s.

**KEY & SOLUTIONS**

**CLASSROOM WORKSHEET**

1. 4 2. 3 3. 2 4. 1 5. 1 6. 2 7. 2
8. 4 9. 4 10. 4 11. 4 12. 4 13. 2 14. 3
15. 1 16. 4 17. 1 18. 1 19. 3

**HOME WORKSHEET**

1. 1 2. 4 3. 2 4. 2 5. 2 6. 1 7. 4
8. 4 9. 3 10. 2 11. 2 12. 1 13. 2 14. 2
15. 1 16. 1 17. 4